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Health and Safety Executive

Installation permitting guidance for hydrogen and fuel cell stationary applications: UK version

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Installation permitting guidance for hydrogen and fuel cell stationary applications: UK version

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The HYPER project, a specific targeted research project (STREP) funded by the European Commission under the Sixth Framework Programme, developed an Installation Permitting Guide (IPG) for hydrogen and fuel cell stationary applications. The IPG was developed in response to the growing need for guidance to foster the use and facilitate installation of these systems in Europe. This document presents a modified version of the IPG specifically intended for the UK market. For example reference is made to UK national regulations, standards and practices when appropriate, as opposed to European ones.

The IPG applies to stationary systems fuelled by hydrogen, incorporating fuel cell devices with net electrical output of up to 10 kWel and with total power outputs of the order of 50 kW (combined heat + electrical) suitable for small back up power supplies, residential heating, combined heat-power (CHP) and small storage systems. Many of the guidelines appropriate for these small systems will also apply to systems up to 100 kWel, which will serve small communities or groups of households. The document is not a standard, but is a compendium of useful information for a variety of users with a role in installing these systems, including design engineers, manufacturers, architects, installers, operators/maintenance workers and regulators.

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EXECUTIVE SUMMARY

Objectives

The HYPER project started on 1 November 2006 and ended in February 2009. The work programme of the HYPER project was structured around the development of an installation permitting guide (IPG) which includes:

- An assessment of current knowledge on installation requirements of small stationary hydrogen and fuel cell systems;
- Detailed case studies of representative installations;
- Modelling and experimental risk evaluation studies to investigate fire and explosion phenomena.

The IPG was developed in response to the growing need for guidance to facilitate small hydrogen and fuel cell stationary installations in Europe. This report is a revised version of the IPG intended for the UK market, reference being made to UK national regulations and standards as opposed to European as appropriate.

This document is not a standard, but is a compendium of useful information for a variety of users with a role in installing these systems, including:

- Design engineers;
- Manufacturers;
- Architects;
- Installers;
- Operators/Maintenance workers;
- Regulators.

The document is organised as follows:

- Introduction and Scope (Chapter 1);
- Introduction to fuel cell systems and their associated hazards (Chapter 2);
- General and Higher Level Requirements (Chapter 3);
- System Specific and Siting Considerations (Chapter 4);
- Permitting Route (Chapter 5);
- Appendices.

The IPG applies to stationary systems fuelled by hydrogen, incorporating fuel cell devices with net electrical output of up to 10kWel and with total power outputs of the order of 50kW (combined heat + electrical) suitable for small back up power supplies, residential heating, combined heat-power (CHP), and small storage systems. Many of the guidelines appropriate for these small systems will also apply to systems up to 100 kWel, which will serve small communities or groups of households.

Recommendations

The complexity of the permitting route required for a particular installation should be proportionate to the scale, intended use and location of the installation. Residential installations are likely to require a simpler permitting route than a commercial or industrial installation. It is recommended, however, that any permitting route should comprise at least the following five steps.

Step 1. Undertake a risk assessment to identify the hazards and the measures to be implemented to eliminate or mitigate their effects. The principal hazards will be fire and explosion ones, but other hazards, e.g. electrical, pressure and weather (for outdoor locations) related, need to be taken into account. Hazards that are likely to arise during the lifetime of the installation also need to be considered. This would include those hazards associated with installation of the equipment, start up and shutdown of the equipment, delivery of consumables (eg gas cylinders) and maintenance and repair. For domestic installations a fairly basic risk assessment will be sufficient and in some cases one may not be required at all, e.g. for an integrated CHP system. In these cases it is proposed that all that is required is that the equipment is installed according to the manufacturer's instructions, as in drawing up these instructions the manufacturer will have undertaken a risk assessment.

Step 2. Check the equipment used in the installation complies with the essential health and safety requirements of all applicable EU Directives. For fuel cells and associated equipment the applicable Directives will include the ATEX Directives, Pressure Equipment Directive, Machinery Directive, Gas Appliances Directive, Low Voltage Directive and Electromagnetic Compatibility Directive.

Step 3. Check the installation meets national legislation dealing with planning approval, building regulations and fire regulations. Installations that can export surplus electricity generated back to the distribution grid will also need to meet any regulations for interconnectivity of supplies.

Step 4. The equipment is installed and maintained by a competent person.

Step 5. Inform the local fire brigade of the location and type of installation and especially for the more complex installations give the opportunity to visit and familiarise themselves with the installation. Of particular interest would be the location and quantity of any hydrogen stored on the site. For domestic installations it would also be prudent to inform the property insurers of the installation.

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1 INTRODUCTION AND SCOPE

1.1 HOW THE DOCUMENT WAS PRODUCED

The HYPER project started on 1 November 2006 and ended in February 2009. The work programme of the HYPER project was structured around the development of an installation permitting guide (IPG)[1] which includes:

- An assessment of current knowledge on installation requirements of small stationary hydrogen and fuel cell systems;
- Detailed case studies of representative installations;
- Modelling and experimental risk evaluation studies to investigate fire and explosion phenomena.

This specific targeted research project (STREP) was funded by the European Commission under the Sixth Framework Programme and contributes to the Implementation of the Thematic Priority 'Sustainable Energy Systems', Contract No 039028.

The IPG was developed in response to the growing need for guidance to facilitate small hydrogen and fuel cell stationary installations in Europe. This report is a revised version of the IPG intended for the UK market, reference being made to UK national regulations and standards as opposed to European as appropriate.

1.2 HOW TO USE THE DOCUMENT

This document is not a standard, but is a compendium of useful information for a variety of users with a role in installing these systems, including:

- Design engineers;
- Manufacturers;
- Architects;
- Installers;
- Operators/Maintenance workers;
- Regulators.

The document is organised as follows:

- Introduction and Scope (Chapter 1);
- Introduction to fuel cell systems and their associated hazards (Chapter 2);
- General and Higher Level Requirements (Chapter 3);
- System Specific and Siting Considerations (Chapter 4);
- Permitting Route (Chapter 5);

- Appendices.

Although it is envisaged that the information may be of interest to all user groups, an effort has been made to organise information for ease of use by each user group, particularly in Chapter 3. Chapter 4 contains additional information relating to specific systems as well as details on siting considerations.

The information in this document provides guidance on some safety aspects of the equipment. This is not a substitute for meeting applicable standards, codes and regulations. Relevant standards, codes and regulations are referenced, where available, in the text and Appendix 1 gives a listing of current codes and standards. As many standards and codes are currently in development or only recently adopted, and system designs have yet to be finalised by many manufacturers, it may be some time before we can reasonably expect equipment certification to these codes and standards. Certification, including CE marking, is not required for demonstration prototypes. It is hoped that the guidance provided in this document can facilitate demonstration and early market installations. A list of abbreviations used in this document is available in Appendix 6. References are provided in Appendix 7.

1.3 SCOPE

The IPG provides a structured analysis of known documents relevant for permitting hydrogen and fuel cell systems in the UK, and documents best practice for the installation of different generic types of hydrogen and fuel cell systems. It also provides guidance on issues not properly dealt with in existing documents, and, therefore, provides the basis for harmonised permitting guidance. The IPG takes account of the already established permitting requirements for natural gas appliances.

The IPG applies to stationary systems fuelled by hydrogen, incorporating fuel cell devices with net electrical output of up to 10kWel (small according to IEC 62282.3.3:2007[2]), and with total power outputs of the order of 50kW (combined heat + electrical) suitable for small back up power supplies, residential heating, combined heat-power (CHP), and small storage systems.

Many of the guidelines appropriate for these small systems will also apply to systems up to 100 kWel which will serve small communities or groups of households.

2 BACKGROUND

2.1 FUEL CELL SYSTEMS

2.1.1 Types of fuel cell

A fuel cell is an electrochemical device that combines hydrogen and oxygen to produce electricity, heat and water. The hydrogen may be produced as a by-product of a chemical process, extracted from any hydrocarbon fuel such as natural gas, gasoline, diesel, or methanol via a fuel reformer, or by electrolysis of water. The oxygen is usually obtained from the ambient air around the fuel cell. In some cases where hydrogen is produced by electrolysis, the oxygen co-produced may be used in the fuel cell.

Fuel cells can be loosely grouped into those with acidic electrolytes, those where the electrolyte is alkaline, and cells that operate at very high temperatures.

Successful examples of acidic electrolyte fuel cells are the proton exchange membrane or polymer electrolyte membrane fuel cells (PEMFCs), that use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst, and the phosphoric acid fuel cells (PAFCs) that use liquid phosphoric acid as an electrolyte (the acid is contained in a Teflon-bonded silicon carbide matrix) and porous carbon electrodes containing a platinum catalyst. PEMFCs are generally designed to be operated at lower temperatures, although some may operate at around 80°C, while PAFCs typically operate at temperatures between 150°C to 200°C.

Alkaline electrolyte fuel cells (AFCs) use an aqueous solution of potassium hydroxide as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. Most AFCs operate at temperatures of between 100°C and 250°C, but new designs operate at lower temperatures of between 20°C to 70°C.

High temperature fuel cells include molten carbonate fuel cells (MCFCs) and solid oxide fuel cells (SOFCs). MCFCs use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminium oxide and operate at 650°C and above. SOFCs use a hard, non-porous ceramic as the electrolyte and operate usually at around 1,000°C. Ongoing research is aimed at reducing this operating temperature down to 550-700°C.

2.1.2 Components of a fuel cell system

All fuel cells work broadly on the same principle:

- Hydrogen or a hydrogen-rich fuel is fed to the anode, where a catalyst separates hydrogen's negatively charged electrons from positively charged ions (protons).

- At the cathode, oxygen combines with electrons, and in some cases with species such as protons or water, resulting in water or hydroxide ions respectively.

- For polymer electrolyte membrane and phosphoric acid fuel cells, protons move through the electrolyte to the cathode to combine with oxygen and electrons to generate water.

- The electrons from the anode side of the cell cannot pass through the membrane to the positively charged cathode so they must travel around it via an electric circuit to reach the other side of the cell. This movement of electrons is an electric current.

The design of fuel cell systems can vary significantly depending on the fuel cell type and application. However most fuel cell systems consist of four basic components:

1. A set or stack of individual cells consisting of an electrolyte sandwiched between two thin electrodes.

2. A fuel cell processor/reformer that converts the hydrogen-rich fuel into a form usable by the fuel cell, an electrolyser or a hydrogen storage system (tank or transportable cylinders). Most fuel cell systems use pure hydrogen or hydrogen-rich fuels, such as methanol, gasoline, methane, diesel or gasified coal, to produce electricity. These fuels are passed through onboard internal reformers within the fuel cell itself, or though external reformers that extract the hydrogen from the fuel.

3. Power-conditioning equipment that converts the direct current produced by the fuel cell into alternating current.

4. A number of subsystems to manage air, water, thermal energy and power.

Although all fuel cell power plants contain these components, the assembly of these components into the actual equipment is very important.

In addition, a heat recovery system is typically used in high-temperature fuel cell systems that are used for stationary applications where the excess energy in the form of heat can be used to produce steam or hot water or converted to electricity.

2.2 HAZARDS ASSOCIATED WITH FUEL CELL INSTALLATION AND OPERATION

2.2.1 Hazards of fuel cells other than hydrogen

Many fuel cells use hydrogen produced by the reforming of hydrocarbon fuels; other high temperature fuel cells are able to utilise suitable hydrocarbons directly. The processing and/or use of these hydrocarbon fuels will produce carbon dioxide. Appropriate measures, such as containment and ventilation, should be taken to ensure that any carbon dioxide effluent stream is effectively discharged and does not produce an asphyxiation risk[3].

Natural gas (methane) is lighter than air and will tend to diffuse upwards, but at a much slower rate than hydrogen. The explosion limits for natural gas (5-15% v/v) are also much narrower than hydrogen. The characteristics of both fuels should be considered for any dual fuel systems. The pipe work and equipment used to supply natural gas should also be suitable and designed to an appropriate standard[4].

Liquefied petroleum gas (LPG) is considerably heavier than air, especially when cold, for example when taken directly from a liquid storage vessel. In the event of a leak, LPG vapour will usually percolate downwards and may accumulate on the floor or in low-lying sumps, rapidly producing a flammable atmosphere. Mixtures containing 2-10% v/v LPG in air will readily ignite and explode[5]. The significant differences in the buoyancy and dispersion characteristics of the two fuels should be carefully considered in systems where LPG and

hydrogen may both be present. The pipe work and equipment used to store and supply LPG fuel should also be suitable and be designed to an appropriate standard[4].

Methanol can be used directly by some types of fuel cell. This fuel has some hazards that demand particular attention. In addition to being a highly flammable liquid, methanol is also toxic by inhalation, ingestion and notably, by skin absorption[6]. Appropriate precautions such as containment and ventilation should be taken to prevent spillages and the accumulation of hazardous methanol/air mixtures whenever it is used.

Compared to the hazards associated with more conventional equivalents to fuel cells e.g. natural gas boilers and batteries, some different hazards have to be taken into account, including not only the fuel cell but also the means of fuel production, storage and transportation.

2.2.2 Fire and explosion hazards

The estimation of hazards and hazard levels is essential to the consideration of accidental consequences, e.g. overpressures, thermal radiation, the throw of debris or missiles, and the damage level or the vulnerability of the receiving objects. In chemical fires/explosions that are usually exothermal oxidation reactions, a great proportion of the combustion energy is carried by the developing blast wave uniformly distributed in all directions.

Many flammable gases are widely in use today, such as methane, propane etc. Without appropriate measures being taken, a gas release and subsequent fire and explosion can occur. Hydrogen has some significantly different properties from these more commonly used gases which need to be fully appreciated to achieve comparable levels of safety.

Hydrogen for use in fuel cells may be stored in a number of ways:

- As a compressed gas - normally in conventional gas cylinders at a pressure of 200bar, but this pressure may be increased in specialist applications to increase energy storage density.
- As a cryogenic liquid - hydrogen is stored as a liquid below -250 ^{o}C therefore, consideration should be given to cold burns, condensation of oxygen-enriched atmospheres, and the way in which a liquid spill may develop into a flammable cloud. It should be appreciated that the vapour produced by a liquid spill will not initially be buoyant due to its low temperature.
- Complex hydrides are also used as a hydrogen storage medium, generally based on sodium aluminium hydrides or similar materials. These materials are flammable solids and can react violently with water to produce hydrogen and a corrosive aqueous solution. Hydride storage systems can be suitably designed to avoid these hazards.

2.3 PROPERTIES AND CHARACTERISTICS OF HYDROGEN

Hydrogen is a colourless, odourless gas that is lighter than air. The use of odorants to detect leaks[7] is being investigated, however, all the odorant chemicals so far considered have been rejected due to concerns regarding their potential to 'poison' the fuel cell membrane catalysts. Furthermore, they may have limited effectiveness for small leaks, as the odorant molecules will inevitably be much larger than the hydrogen molecules.

Hydrogen has many characteristics which are significantly different from conventional fuels, and which it is important to take into account when designing and installing a fuel cell system.

A comparison of the characteristics of hydrogen against two other widely used fuels, natural gas and LPG is given in Table 1.

Table 1 - Characteristics of hydrogen, dry natural gas and gaseous propane

Property	Dry natural gas (methane)	LPG (propane)	Hydrogen
Density (Kg/m^3) *	0.65	1.88	0.090
Diffusion coefficient in air (cm^2/s) *	0.16	0.12	0.61
Viscosity (g/cm-s x 10^{-5}) *	0.651	0.819	0.083
Ignition energy in air (mJ)	0.29	0.26	0.02
Ignition limits in air (vol %)	5.3 – 15.0	2.1 – 9.5	4.0 – 75.0
Auto ignition temperature (C)	540	487	585
Specific heat at constant pressure (J/gK)	2.22	1.56	14.89
Flame temperature in air (C)	1875	1925	2045
Quenching gap (mm) *	2	2	0.6
Thermal energy radiated from flame to surroundings (%)	10-33	10 - 50	5-10
Detonability limits (vol % in air)	6.3-13.5	3.1 – 7.0	13-65
Maximum burning velocity (m/s)	0.43	0.47	2.6

* at normal temperature and pressure – 1 atmosphere and 20°C

2.3.1 Propensity to leak

2.3.1.1 Low viscosity

Hydrogen gas has a very low viscosity and so it is very difficult to prevent hydrogen systems from developing leaks. Pipe work that was 'leak tight' when pressure-tested with nitrogen will often be found to leak profusely when used on hydrogen duty.

Hydrogen leakage through welds, flanges, seals, gaskets, etc is an important consideration and an important design and operational issue for hydrogen systems.

The use of suitable sealing interfaces and appropriate components within a hydrogen system, however, will significantly reduce the likelihood of this occurring if fitted by a competent person. For high-pressure storage systems, hydrogen would leak nearly three times faster than natural gas and over five times faster than propane. However the low energy density of hydrogen means that it produces substantially lower energy leakage rates.

2.3.1.2 Extremely high diffusivity

Hydrogen is very much lighter than air and is also very diffusive. Thus, unlike heavier gaseous fuels, if a hydrogen leak occurs in an open or well-ventilated area its diffusivity and buoyancy will help to reduce the likelihood of a flammable mixture forming in the vicinity of the leak.

However, as with other gases when leaks occur within poorly ventilated or enclosed areas, the concentration may rapidly reach dangerous levels. Due to its lightness, hydrogen will concentrate in elevated regions of an enclosed space, whereas other gases, dependent upon their relative mass, will concentrate at ground level (LPG) or at elevation (CNG). If unprotected electrical equipment or other sources of ignition are present, the risk from explosion could be considerable.

As hydrogen diffuses more rapidly through air and through solid materials compared to other fuel gases such as methane or propane, it will usually disperse more rapidly if released, although buoyancy effects are less significant for high momentum releases from high-pressure hydrogen systems. When harnessed through intelligent equipment design and layout, this buoyancy and hydrogen's rapid dispersion rate can become a significant safety asset.

2.3.1.3 High buoyancy

The buoyancy of hydrogen can also be used to manage the risk normally associated with fuel handling by segregating the hydrogen from foreseeable sources of ignition using internal partitions and bulkheads and differential pressurisation. This can also be done by locating all potential sources of ignition well below the level of the equipment from which hydrogen may leak and accumulate, and ensuring adequate ventilation and safe discharge of the exhaust.

2.3.2 Propensity to cause embrittlement

Hydrogen can cause embrittlement of high strength steels, titanium alloys and aluminium alloys with cracking and catastrophic failure of the metals at stress below the yield stress. This is most commonly related to the carbon content of metallic alloys. Pure, unalloyed aluminium, however, is highly resistant to embrittlement. The industry standard for components in hydrogen service is grade 316 stainless steel. Cupro-nickel is also suitable for hydrogen service and copper can be used for low-pressure applications.

2.3.3 Propensity to ignite

2.3.3.1 Wide flammability range

Hydrogen readily forms an explosive mixture with air. The range of hydrogen/air mixtures that will explode is wide. Mixtures containing from as little as 4% v/v hydrogen, which is the lower explosive limit (LEL), up to as much as 75% v/v, which is the upper explosive limit (UEL), may propagate a flame. The wide range of flammability of hydrogen-air mixtures compared to propane and methane-air mixtures is, in principle, a disadvantage. There are, however, only minor differences between the LEL of hydrogen and that of methane or propane. The LEL of hydrogen is considered by many experts to have a greater significance in hazard ranking than the width of the fuel's flammable range. Furthermore, in the case of low momentum releases, the dispersion characteristics of hydrogen will make it less likely that a flammable mixture will form.

2.3.3.2 Very low ignition energy

The energy necessary to initiate a hydrogen/air explosion is very small. The ignition energy for a 2:1 hydrogen/oxygen mixture is only about 0.02 mJ. This is less than one tenth that of other fuels such as methane, LPG or petrol. Even very small sparks, such as those produced by wearing certain types of clothing, are capable of igniting hydrogen/air mixtures and causing an explosion.

2.3.3.3 *Spontaneous ignition*

Hydrogen has the possibility to spontaneously ignite on sudden release from pressurised containers.

2.3.4 Consequences of a fire / explosion

2.3.4.1 *Invisible flame*

Hydrogen burns with an invisible flame making it difficult to detect a hydrogen fire. This apparent low emissivity of hydrogen flames (total heat flux radiated) may reduce the heat transfer by radiation to objects near the flame, thus reducing the risks of secondary ignition and burns. However, such effects have not been fully quantified and further work is needed in this area.

2.3.4.2 *Rapid burning rate*

The maximum burning velocity of a hydrogen-air mixture is about eight times greater than those for natural gas and propane air mixtures. The high burning velocity of hydrogen makes it difficult to confine or arrest hydrogen flames and explosions, particularly in closed environments. In its favour, however, this rapid rate of deflagration means that hydrogen fires transfer less heat to the surroundings than other gaseous fuel fires, thereby reducing the risk of creating secondary fires in neighbouring materials. Another downside of a higher burning velocity of hydrogen is that for a given scenario hydrogen would result in higher explosion pressures and rates of pressure rise than other fuels.

2.3.5 Possibility of detonation

Hydrogen/air mixtures have a greater propensity to detonate than mixtures of air with other more common flammable fuels. Detonations cause much more damage and are far more dangerous than ordinary explosions (deflagrations). However, due to the rapid dispersal characteristics of hydrogen, this is only likely to occur in a confined or congested space.

3 GENERAL AND HIGHER LEVEL REQUIREMENTS

Guidance given in this chapter is of a general nature and is taken from UK legislation and relevant European Community directives. If it is necessary to certify part or all of a fuel cell system using these directives, the full documents should be obtained to assess conformity, unless using a third party for certification. The process of CE certification is briefly described in section 3.1.1.

3.1 DESIGN AND MANUFACTURING REQUIREMENTS

3.1.1 CE certification

CE marking is mandatory in the UK for certain product groups which indicates conformity with the essential health and safety requirements set out in a number of EU directives (e.g. machinery - 2006/42/EC[8], low voltage - 2006/95/EC[9], gas appliances - 90/396/EEC[10], ATEX equipment directive - 94/9/EC[11]).

CE conformity marking concerns the design, manufacture, placing on the market and entry into service of a product. The CE marking must be affixed by the manufacturer or his agent established in the EC.

Depending on the directive concerned, certification is either through self-declaration or through examination and assessment by a notified body.

The manufacturer bears the ultimate responsibility for the conformity of the product. He has to issue a Declaration of Conformity which includes his identity, a list of EU directives he declares compliance with, a list of standards the product complies with, and a legally binding signature.

The basis of the conformity assessment is the Technical Construction File (also referred to in some directives as the technical file or the technical demonstration), which is a compilation of documents containing the product design and security measures that make it safe.

Prototype and demonstration units are not required to have CE marking.

A number of 'Agreement of Mutual Recognition of Conformity Assessment' between the EC and third countries (USA, Canada, Australia, Japan, New Zealand, and Israel) allows industries based in those countries to use local certification organisations accredited for the specific directive.

To assist fuel cell components manufacturers, relevant directives and the UK regulations that implement the requirements of the directives are listed in Table 2. A checklist that can be used when seeking EC certification, together with further details on the CE mark, the Technical Construction File and the EC Declaration of Conformity can be found in Appendix 3.

Table 2 - Relevant directives requiring compulsory CE marking

Directive	Applicable to:	Comments
90/396/EEC - Gas Appliance Directive[10] The Gas Appliances (Safety) Regulations 1995[12]	Appliances burning gaseous fuels used for cooking, heating, hot water production, refrigeration, lighting or washing and having, where applicable, a normal water temperature not exceeding 105°C.	Strictly only applicable to fuel cells where the primary function is heating. However, some principles on general health and safety considerations may still be useful.
94/9/EC - ATEX Equipment Directive[11] Equipment and protective Systems for Use in Potentially Explosive Atmospheres (EPS) Regulations 1996[13]	Equipment (electrical and non-electrical) and protective systems intended for use in potentially explosive atmospheres.	Hazardous area classification must be carried out to assess potential locations and likelihoods of an explosive atmosphere being present to ensure that any equipment cannot act as a source of ignition.
97/23/EC - Pressure Equipment Directive[14] Pressure Equipment Regulations (PER) 1999[15]	This directive applies to the design, manufacture and conformity assessment of pressure equipment with a maximum allowable pressure greater than 0,5 bar above atmospheric pressure for the maximum/minimum temperatures for which the equipment is designed for gases, liquids and vapours.	The certification process by the Pressure Equipment Directive, both certification by the manufacturer and by a notified body, depends on a number of system parameters. These parameters include the hazards posed by the pressurised gas/liquid, the characteristics and dimensions of the equipment and its intended use.

2004/108/CE - Electromagnetic Compatibility Directive[16] The Electromagnetic Compatibility Regulations 2006[17]	Equipment or combinations thereof made commercially available as a single functional unit, intended for the end user and liable to generate electromagnetic disturbance, or the performance of which is liable to be affected by such disturbance.	The manufacturer shall perform an electromagnetic compatibility assessment of the apparatus, on the basis of the relevant phenomena, with a view to meeting the protection requirements set out in the Directive.
2006/95/EC - Low Voltage Directive[9] The Electrical Equipment (Safety) Regulations 1994[18]	Electrical equipment designed for use with a voltage rating of between 50 and 1,000 V for alternating current and between 75 and 1,500 V for direct current.	The electrical equipment should be so designed and manufactured as to ensure protection against the hazards arising from the voltages at which the is used, providing that the equipment is used in applications for which it was made and is adequately maintained.
2006/42/EC - Machinery Directive[8] Supply of Machinery (Safety) Regulations[19,20,21]	Machinery, interchangeable equipment, safety components, lifting accessories, chains, ropes and webbing, removable mechanical transmission devices, partly completed machinery.	The manufacturer or his authorised representative should also ensure that a risk assessment is carried out for the machinery which he wishes to place on the market. For this purpose, he should determine which are the essential health and safety requirements applicable to his machinery and in respect of which he must take measures.

A list of useful codes and standards associated with the various parts of a fuel cell system is given in Appendix 1. A further useful source of information is the BSI published document PD 6686:2006[22]. It discusses the EU and UK legislation intended to minimize the risk of fire and explosion in the process industries and provides a comprehensive guide to the standards, draft standards and other documents that contain technical, practical and organizational information to ensure compliance.

3.1.2 Compliance with EC directives

The manufacturer of a fuel cell and its components, or their authorised representative, must ensure that the relevant EC directives are complied with. Compliance with these directives is mandatory in the UK, however, taking into account the state of the art, demonstration models etc, it may not be possible to meet all the objectives set. In that event, the equipment must, as far as possible, be designed and constructed with the purpose of approaching the objectives detailed

in any relevant directive(s). Table 2 gives a list of relevant directives. An outline of what has to be addressed is given in the sections below.

3.1.3 Risk Assessment

The manufacturer of a fuel cell and its components, or their authorised representative, must ensure that a risk assessment is carried out in order to determine the health and safety requirements that apply to the equipment. The equipment must then be designed and constructed taking into account the results of the risk assessment.

There are technical resources available in many EU member states to assist in preparing risk assessments. These include guidance books, videos, training sessions and consultancy services. These can be found using an internet search engine with the key words "risk assessment"

Further guidance on performing a risk assessment is given in Appendix 5.

3.1.4 Protection against mechanical hazards

The Machinery Directive requires the following aspects to be considered:

- Risk of loss of stability;
- Risk of break-up during operation;
- Risks due to falling or ejected objects;
- Risks due to surfaces, edges or angles;
- Risks related to combined equipment;
- Risks related to variations in operating conditions;
- Risks related to moving parts;
- Choice of protection against risks arising from moving parts;
- Risks of uncontrolled movements.

3.1.5 Protection against electrical hazards

The electrical equipment, together with its component parts, should be made in such a way as to ensure that it can be safely and properly assembled and connected. The following should be addressed:

- Protection against hazards arising from the electrical equipment;
- Protection against hazards which may be caused by external influences on the electrical equipment;
- Electricity supply;
- Static electricity;
- Electromagnetic compatibility.

3.1.6 Protection from flammable gas appliance hazards

The Gas Appliances (Safety) Regulations require the possibility of unburned gas release to be considered.

3.1.7 Protection against fire and explosion hazards

The manufacturer should safeguard against risk of fire and explosion.

For fuel cell components for use in potentially explosive atmospheres the Equipment and protective Systems for Use in Potentially Explosive Atmospheres (EPS) Regulations 1996[13] apply.

The ATEX Workplace Directive (99/92/EC)[23], implemented in the UK by the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002[24], will also apply. Although DSEAR does not specifically require the production of an explosion protection document, as required by the ATEX Workplace Directive, the key requirement of the Regulations is that risks from dangerous substances, e.g. flammable gases, are assessed and controlled.

The DSEAR and EPS Regulations only apply to workplaces and thus would not be applicable to domestic installations.

3.1.8 Protection against pressure related hazards

The Pressure Equipment Regulations (PER) 1999[15] apply to any equipment that could contain pressures in excess of 0.5 bar. The Regulations require the following aspects to be addressed:

- Strength of equipment;
- Provisions to ensure safe handling and operation;
- Means of examination;
- Means of draining and venting;
- Materials for pressure vessels.
- Wear
- Assemblies
- Provisions for filling and discharge
- Protection against exceeding the allowable limits of pressure equipment
- Safety accessories
- Manufacturing procedures
- Marking and labelling
- Operating instructions

At elevated temperatures and pressures, hydrogen attacks mild steels severely, causing decarburisation and embrittlement. This is a serious concern in any situation involving storage or transfer of hydrogen gas under pressure. Proper material selection, e.g. special alloy steels, and technology is required to prevent embrittlement[25].

3.1.9 General health and safety requirements

General health and safety requirements should be addressed with respect to:

- Materials and products;
- External temperatures;
- Errors of fitting;
- Extreme temperatures;
- Noise;
- Vibrations;
- External radiation;
- Emissions of hazardous materials and substances;
- Risk of being trapped in a machine;
- Risk of slipping, tripping or falling;
- Lightning.

3.1.10 Control system requirements

For an appliance equipped with safety and controlling devices, the functioning of the safety devices must not be overruled by the controlling devices (see the BS EN series of standards[26] for control device requirements).

All parts of appliances that are set or adjusted at the stage of manufacture and which should not be manipulated by the user or the installer must be appropriately protected.

Levers and other controlling and setting devices must be clearly marked and give appropriate instructions to prevent any error in handling. Their design must preclude accidental manipulation.

The surface temperature of knobs and levers of appliances must not present a danger to the user.

Other areas that need to be addressed in the design of the control system are:

- Safety and reliability of control systems;
- Control devices;
- Starting;
- Stopping;
- Selection of control or operating modes;
- Failure of the power supply.

3.1.11 Equipment Information, warnings, markings and instructions

The EU Equipment Directives and the UK implementing regulations contain requirements relating to:

- Information and information devices;
- Warning devices;
- Warning of residual risks;
- Marking of equipment;
- Instructions.

3.2 INSTALLATION REQUIREMENTS

Appliances must be correctly installed and regularly serviced in accordance with the manufacturer's instructions.

3.2.1 Installation location

Where practical, particularly for industrial applications, the fuel cell should be located outdoors. Fuel cells for residential applications should be designed, installed, operated and maintained to be safe in typical indoor locations. For non-residential indoor installations, the fuel cell should be located in a well ventilated area in which combustible materials are minimised. In designing the installation consideration should be given as to whether it is necessary to separate the rooms or spaces that enclose the fuel cell installation from other building areas by fire barriers. Use of appropriate protective devices for openings (i.e. doors, shutters, windows, service entries, etc) should also be considered. Voids or openings between the room in which the fuel cell is enclosed and adjacent rooms into which combustion products could pass should be avoided. The shared walls should be gas tight. A check should be made that any automatic fire suppression system installed has been correctly specified for the room or space in which the fuel

cell and associated components are located. All installations should comply with building and fire regulations.

For outdoor installations weather protection may be required. Hydrogen storage cylinders and vessels located outdoors need to be protected from extreme temperatures (below –20°C and above 50°C). Permanently installed hydrogen vessels must be provided with substantial supports, constructed of non-combustible material securely anchored to firm foundations of non-combustible material and protected from accidental impact, e.g. from a vehicle. Transportable compressed gas cylinders and vessels shall be secured against accidental dislodgement and protected from accidental impact. The area around hydrogen installations should be kept free of dry vegetation and combustible matter. If weed killers are used, chemicals such as sodium chlorate, which are a potential source of fire hazard, should not be selected for this purpose.

3.2.2 Ventilation

Natural or forced (mechanical) ventilation can be used to prevent the formation of potentially explosive mixtures. Natural ventilation is the preferred method due to its intrinsic reliability. If forced ventilation is used, then the reliability of the system has to be considered.

Appliances which are not fitted with devices such as flues to avoid a dangerous accumulation of unburned gas or combustion products in indoor spaces and rooms should be used only in areas where there is sufficient ventilation to avoid accumulation to dangerous levels.

3.2.3 Pressure systems

Suitable means must be provided for testing and venting pressure equipment. The risk assessment for the installation should cover the pressurising and venting operations. Adequate means must also be provided to permit cleaning, inspection and maintenance in a safe manner of all pressure systems.

3.2.4 Materials selection for installation

Materials used for the installation of hydrogen and fuel cell equipment must be suitable for such application during the scheduled lifetime unless replacement is foreseen.

Where necessary, adequate allowance or protection against corrosion or other chemical attack must be provided, taking due account of the intended and reasonably foreseeable use. Hydrogen gas dissolved in liquids will permeate into adjoining vessel materials. At elevated temperatures and pressures, hydrogen attacks mild steels severely, causing decarburisation and embrittlement. It is, therefore, vital that if hydrogen is stored or handled under pressure compatible materials, e.g. special alloy steels, are used for pipe work, vessels, etc.

3.2.5 Mechanical and thermal hazards

Equipment must be designed and constructed to minimise the risk of injuries from moving parts and hot surfaces. If there are moving parts, appropriate guarding should be provided to prevent accidental contact or ejection of failed components. Hot components need to be insulated or a means provided of preventing accidental contact.

3.2.6 Slipping, tripping or falling hazards

Access to the equipment should be such that there are no slipping, tripping or falling hazards for personnel delivering supplies, e.g. gas cylinders, undertaking maintenance or carrying out repairs to the installation.

Rooms or enclosures containing equipment should be fitted with measures to prevent a person from being accidentally trapped within it or, if that is impossible, with a means of summoning help.

3.2.7 Lightning protection

Outdoor installations may also need protection against lightning strikes. This can be achieved by fitting a system for conducting the resultant electrical charge to earth and also ensuring all equipment is electrically bonded and earthed.

3.2.8 Gas venting

In electrolyser-fed systems, venting facilities for hydrogen and oxygen should be separate and isolated from each other.

3.2.9 Manual handling

Equipment, or each component part thereof, must:

- be capable of being handled and transported safely;
- be packaged or designed so that it can be stored safely and without damage.

During the transportation of the equipment and/or its component parts, there must be no possibility of sudden movements or of hazards due to instability as long as the equipment and/or its component parts are handled in accordance with the instructions.

Where the weight, size or shape of equipment or its various component parts prevents them from being moved by hand, the equipment or each component part must:

- either be fitted with attachments for lifting gear, or
- be designed so that it can be fitted with such attachments, or
- be shaped in such a way that standard lifting gear can easily be attached.

Where equipment or one of its component parts is to be moved by hand, it must:

- either be easily moveable, or
- be equipped for picking up and moving safely.

Special arrangements must be made for the handling of tools and/or machinery parts which, even if lightweight, could be hazardous.

3.3 REGULATORY APPROVAL CONSIDERATIONS

The approval process may depend on whether the installation is in a work environment (industrial) or a residential environment, and the fact that different authorities have responsibility for the industrial and residential premises.

Furthermore, the process may depend on the fuel used. As some fuel cells, especially those providing combined heat and power, operate on natural gas, these fuel cells may qualify under existing regulations and be treated similarly to a gas boiler. For fuel cells operating on other fuels, in particular hydrogen, which is not currently covered by existing regulations as a fuel

gas, more time may be required for preparing technical information for the approval and for the review of that information.

3.3.1 Building codes and regulations

Building codes and regulations describe a set of rules which specify an acceptable level of safety for constructed objects, both buildings and non-building structures. Their requirements cover issues such as:

- Design and construction to ensure structural stability of the building and adjoining buildings;
- Fire safety, means of escape, prevention of internal and external fire spread and access and facilites for the fire services;
- Preparation and resistance to moisture;
- Control of toxic substances;
- Resistance to the passage of sound;
- Ventilation;
- Hygiene, safety and provision of sanitary and washing facilites;
- Drainage and waste disposal;
- The use of combustion appliances and fuel storage;
- Protection from falling, collision and impact;
- The conservation of fuel and power;
- Access to and use of the building;
- Safety relating to windows, impact, opening and cleaning;
- Electrical safety.

Some buildings may be exempt from these controls such as temporary buildings, buildings not frequented by people (unless close to a building that is), small detached buildings such as garages, garden storage, sheds and huts, and simple extensions such as porches, covered ways and conservatories. However, it is good practice to have exemption confirmed by the appropriate authority prior to construction.

The Building Regulations 2006[27], as amended, lay down the requirements for England and Wales. Approved Documents have been published[28] for the purpose of providing practical guidance on meeting the requirements of the Regulations. For fuel cell installations the most relevant approved documents are Part A Structure, Part B Fire Safety, Part F Ventilation, Part J Combustion Appliances and Fuel Storage, Part L Conservation of Fuel and Power and Part P Electical Safety. Scotland has its own building regulations, the Building (Scotland) Regulations 2004[29], which are broadly in line with the English and Welsh regulations. Guidance on achieving the requirements of the Regulations are given in a series of Technical Handbooks[30].

3.3.2 Regulations

In the UK, the principal regulations covering hydrogen facilities arise from the national legislation passed to implement the ATEX Directives[11,23] and the Pressure Equipment Directive[14]. Their requirements are not specific to hydrogen and would equally apply to any fuel that is capable of generating a flammable atmosphere, for example natural gas or LPG, or equipment that contains a fuel under pressure. For some components of the installation, for example if the hydrogen is produced in-situ by the reformation of natural gas, the requirements of the Gas Appliances Directive[10] may also be applicable.

ATEX is the name commonly given to the framework for controlling explosive atmospheres arising from gases, vapours, mists or dusts, and the standards of equipment and protective systems used in them. It is based on the requirements of two European Directives. The first is Directive 94/9/EC[11] (also known as ATEX 95 or ATEX Equipment Directive) on the approximation of the laws of member states concerning equipment and protective systems intended for use in potentially explosive atmospheres. The EPS Regulations[13] implements the requirements of the Directive in the UK. Any equipment (electrical or non-electrical) or protective system designed, manufactured or sold for use in potentially explosive situations has to comply with the essential health and safety requirements (EHSR) set out in the Regulations. The second is Directive 99/92/EC[23] (also known as ATEX 137 or the ATEX Workplace Directive) on the minimum requirements for improving the health and safety protection of workers potentially at risk from explosive atmospheres. DSEAR[24] implements the requirements of the ATEX Workplace Directive in the UK. The key requirement of DSEAR is that risks from dangerous substances, e.g. flammable gases, are assessed and controlled.

As the ATEX Directives and thus the DSEAR and the EPS Regulations only apply to the workplace, hydrogen fuel cells installed in domestic premises are outside their scope. Nonetheless the hazard identification process required by DSEAR would serve as a useful model for assessing the safety requirements of domestic installations.

The Pressure Equipment Regulations (PER) 1999[15], implementing the Pressure Equipment Directive (97/23/EC)[14], apply to the design, manufacture and conformity assessment of pressure equipment that is subjected to an internal pressure greater than 0.5 bar above atmospheric pressure. It covers equipment such as pressure vessels, heat exchangers, steam generators, boilers, piping, safety devices and pressure accessories. Thus some of the components of a hydrogen fuel cell installation may fall within the scope of the Directive, although these are usually bought on the market as certified products. Each affected item of pressure equipment has to be assigned into a hazard category according to specific criteria, which then determines the overall essential safety requirements to be met. Depending on the categories, different conformity assessment options are permitted to demonstrate compliance by variants on quality assurance, direct inspection or surveillance of testing by the Notified Body. It is recommended that advice from consultants who specialise in pressure systems be sought in selecting the most appropriate conformity option, as an inappropriate choice can lead to unnecessary delays and costs in demonstrating compliance.

The Gas Appliances Directive[10], implemented in the UK The Gas Appliances (Safety) Regulations 1995[12], applies to appliances burning gaseous fuels used for cooking, heating, hot water production, refrigeration, lighting or washing and having, where applicable, a normal water temperature not exceeding 105°C. It also specifies requirements for certain fittings, including safety, regulating and controlling devices and sub-assemblies. For the purposes of this directive a 'gaseous fuel' means any fuel that is in a gaseous state at a temperature of 15°C at a pressure of 1 bar. Though fuel cells do not burn gaseous fuels and should be excluded from the scope of the Directive, guidance issued on what appliances are covered by the Directive

includes fuel cells where the primary function is heating. The essential safety requirements of the Directive could also be applied to certain components of the installation, e.g. a reformation unit for generating hydrogen and safety, regulating and control devices.

Hydrogen fuel cell installations would also need to comply with the relevant parts of the Supply of Machinery (Safety) Regulations[19,20,21], the Electrical Equipment (Safety) Regulations 1994[18], the Electromagnetic Compatibility Regulations 2006[17], as well as EU directives and UK legislation covering general health and safety.

Further information on the procedures for demonstrating conformity with EU directives and obtaining CE marking for equipment is given in 3.1 and Appendix 3.

3.4 OPERATIONAL/MAINTENANCE CONSIDERATIONS

3.4.1 Equipment maintenance

Adjustment and maintenance points must be located outside danger zones. It must be possible to carry out adjustment, maintenance, repair, cleaning and servicing operations while equipment is at a standstill. If one or more of the above conditions cannot be satisfied for technical reasons, measures must be taken to ensure that these operations can be carried out safely. In the case of automated equipment and, where necessary, other equipment, a connecting device for mounting diagnostic fault-finding equipment must be provided. Automated equipment components that have to be changed frequently must be capable of being removed and replaced easily and safely. Access to the components must enable these tasks to be carried out with the necessary technical means in accordance with a specified operating method.

3.4.2 Access to operating positions and servicing points

Equipment must be designed and constructed in such a way as to allow access in safety to all areas where intervention is necessary during operation, adjustment and maintenance of the equipment.

3.4.3 Isolation of energy sources

Equipment must be fitted with means to isolate it from all energy sources. Such isolators must be clearly identified. They must be capable of being locked if reconnection could endanger people. Isolators must also be capable of being locked where an operator is unable, from any of the points to which he has access, to check that the energy is still cut off. In the case of equipment capable of being plugged into an electricity supply, removal of the plug is sufficient, provided that the operator can check from any of the points to which he has access that the plug remains removed. After the energy is cut off, it must be possible to dissipate normally any energy remaining or stored in the circuits of the equipment without risk to people. As an exception to the requirement laid down in the previous paragraphs, certain circuits may remain connected to their energy sources in order, for example, to hold parts, to protect information, to light interiors, etc. In this case, special steps must be taken to ensure operator safety.

3.4.4 Operator intervention

Equipment must be so designed, constructed and equipped that the need for operator intervention is limited. If operator intervention cannot be avoided, it must be possible to carry it out easily and safely.

3.4.5 Cleaning of internal parts

The equipment must be designed and constructed in such a way that it is possible to clean internal parts that have contained dangerous substances or preparations without entering them; any necessary unblocking must also be possible from the outside. If it is impossible to avoid entering the equipment, it must be designed and constructed in such a way as to allow cleaning to take place safely.

4 SYSTEM-SPECIFIC AND SITE CONSIDERATIONS

When installing a hydrogen fuel cell system, many safety factors need to be taken into account. While Chapter 3 dealt with the general safety considerations, this chapter deals with system-specific and siting considerations, mainly focused on fire and explosion hazards. When seeking to control the risks associated with using hydrogen, it is important firstly to take all reasonable steps to prevent a loss of containment of hydrogen, secondly to ensure if there is a leak that a flammable atmosphere cannot accumulate, thirdly to control potential ignition sources where flammable atmospheres may accumulate, and finally, to use suitable protection against the fire and explosion hazards. The experimental and modelling programmes in the HYPER project considered scenarios related to the system siting, and the reader is referred to the IPG[1] and the HYPER website[31] for further information on the results of these work programmes.

It should be noted that many of the regulations and standards cited in this chapter would not be applicable or relevant to residential applications. For example, the DSEAR[24] and EPS Regulations[13] only apply to the workplace. Nonetheless it is recommended that the general principles in DSEAR be adopted for identifying hazards and implementing prevention and protection measures for residential applications.

4.1 HYDROGEN GENERATION

4.1.1 Generation options

Hydrogen can be produced at large central production facilities and delivered to the point of use or produced at the point of use, an option that is not available for conventional fuels like natural gas. For small-scale stationary applications, the usual method of delivery from production facilities to site is by single transportable cylinders or manifolded packs of cylinders. An option for the future is via the existing natural gas transmission system. Work is currently in progress to explore the feasibility of using the existing system to transport mixtures of natural gas and hydrogen, with the hydrogen being separated out at the point of use[32].

Methods of on-site production include reforming of natural gas, the gas being supplied by the existing natural gas distribution network and the electrolysis of water. Production units being developed for domestic applications potentially have the capability to generate enough hydrogen to supply a fuel cell (to provide electricity and heating for the home) and re-fuel a hydrogen-powered car. The widespread adoption of on-site production would reduce the need for large-scale hydrogen production facilities and the associated distribution and storage infrastructure.

4.1.2 Standards and guidance

General guidance on the safety of hydrogen systems can be found in the International Standard Organisation's Technical Report ISO/TR 15916:2004[33].

The International Standards Organisation (ISO) has published or is developing standards specifically dealing with hydrogen production systems. ISO 16110-1:2007[34] covers the safety of stationary hydrogen generators intended for indoor or outdoor commercial, industrial and residential applications using fuel-processing technologies. It applies to packaged, self-contained or factory matched generation systems with a capacity of less than 400 m^3/h that convert the input fuel to a hydrogen-rich stream of composition and condition suitable for the type of device using the hydrogen, e.g. a fuel cell. Input streams include one or a combination of the following fuels:

- natural gas and other methane-rich gases derived from biomass or fossil fuel sources;
- fuels derived from oil refining such as petrol, diesel and LPG; alcohols, esters, ethers, aldehydes, ketones and other hydrogen-rich organic compounds; and
- gaseous mixtures containing hydrogen.

Part 2[35] of the standard dealing with procedures to determine the efficiency of these types of generator is under development.

ISO has also published a standard (ISO 22734-1:2008)[36] on hydrogen generators using the water electrolysis process for industrial and commercial applications. It covers the construction, safety and performance requirements of packaged or factory matched generators for both indoor and outdoor use. Hydrogen generators that can also be used to generate electricity such as reversible fuel cells are excluded from the scope of the standard. Part 2[37] of the standard, covering generators for residential applications, is under development with publication expected in May 2010

Hydrogen fuel cells such as PEMFC and AFC usually require a hydrogen supply of high purity, as their performance and operational life can be adversely affected by even trace impurities in the hydrogen supply. This is less so for SOFC. ISO standard ISO 14687:1999[38] deals with product specification for hydrogen fuel. The European Industrial Gases Association (EIGA) document on gaseous hydrogen stations ((IGC Doc 15/06/E)[39] contains some guidance on the operation of purification systems.

4.2 HYDROGEN CONTAINMENT AND PIPING

Measures to prevent the release of dangerous substances should be given the highest priority. The likelihood of a leak occurring can be minimised by using high quality engineering.

Particular attention should be paid to the design, installation, operation and maintenance of hydrogen handling equipment in order to reduce the likelihood and size of any leak[33]. The following points should be taken into account as recommended best practices[3]:

- Ensure that the storage equipment, pipe work and connections conform to an approved standard for hydrogen equipment[39];
- Ensure that maintenance work if effectively controlled and is only carried out by authorised competent people;
- Minimise the frequency with which connections are made and broken;
- For gaseous supply, use appropriate refillable stationary storage in preference to regularly replacing large numbers of separately connected cylinders;
- Use the minimum amount of storage that is practical without disproportionately increasing other hazards, such as those associated with moving gas cylinders;
- Use the minimum length and size of pipe work that is appropriate;
- Use the minimum length of high pressure pipe work, from the pressure source to the high pressure regulator;

- Where possible, use as small a diameter and operating pressure as possible, flow restriction may also be used on high pressure pipe work, in order to minimise mass flow of hydrogen and hence the consequences of any unintended releases (see Figure 1);

- Minimise hydrogen inventories where possible;

- Minimise the number of joints by using continuous lengths of pipe work wherever practicable;

- Where possible use fusion joints (welded or brazed) to join pipe work, flange/threaded connectors may be used where necessary;

- Give due consideration to the risk of fatigue due to vibrations in pipes;

- Ensure that the system is leak tested before use in a manner appropriate to hydrogen systems[39];

- Use a high pressure relief valve downstream from the high pressure regulator that is able to vent into a 'safe' place where hydrogen gas cannot accumulate but can freely disperse;

- Suitable isolation valves, with locking facilities, should be used to enable isolation of sections of pipe work/system for routine maintenance and in emergencies;

- All hydrogen handling equipment and piping shall be identified and appropriately labelled;

- Carry out appropriate inspections of the system at suitable regular intervals and record the results;

- Review the operation and maintenance history at suitable intervals.

When high-pressure storage is used, it should be designed and built to an appropriate design code or standard and located in a secure open-air compound[39]. Measures appropriate to the location should be taken to prevent unauthorised access, vandalism and impact from vehicles.

Cryogenic hydrogen storage installations should be constructed to an appropriate code and located in a suitable open-air position and not within an occupied building[40]. Low temperature storage installations should incorporate suitable measures to prevent oxygen-rich liquid air, a powerful oxidising agent, from condensing on uninsulated surfaces exposed to liquid hydrogen temperatures. To avoid the risk from fire, potentially flammable materials, including asphalt and tarmac, should not be present beneath pipe work where condensation may occur.

Only appropriate pipe work and fittings for the supply of hydrogen should be used[7,39]. Cupro-nickel and stainless steel are preferred materials for high-pressure pipe work whereas copper can be used for lower pressures. All pipe work joints should be brazed or welded where possible. Flanged or screwed joints may be used where necessary. Suppliers should be able to provide information on the operating parameters of pipe work and fitting, and the standards used for their manufacture.

Compression joints are generally not recommended for use on hydrogen systems as it is difficult to achieve and maintain these in a leak-free condition. Where their use is considered essential, such as on small-bore pipe work, they should be suitable for the duty and used in strict accordance with the manufacturer's instructions.

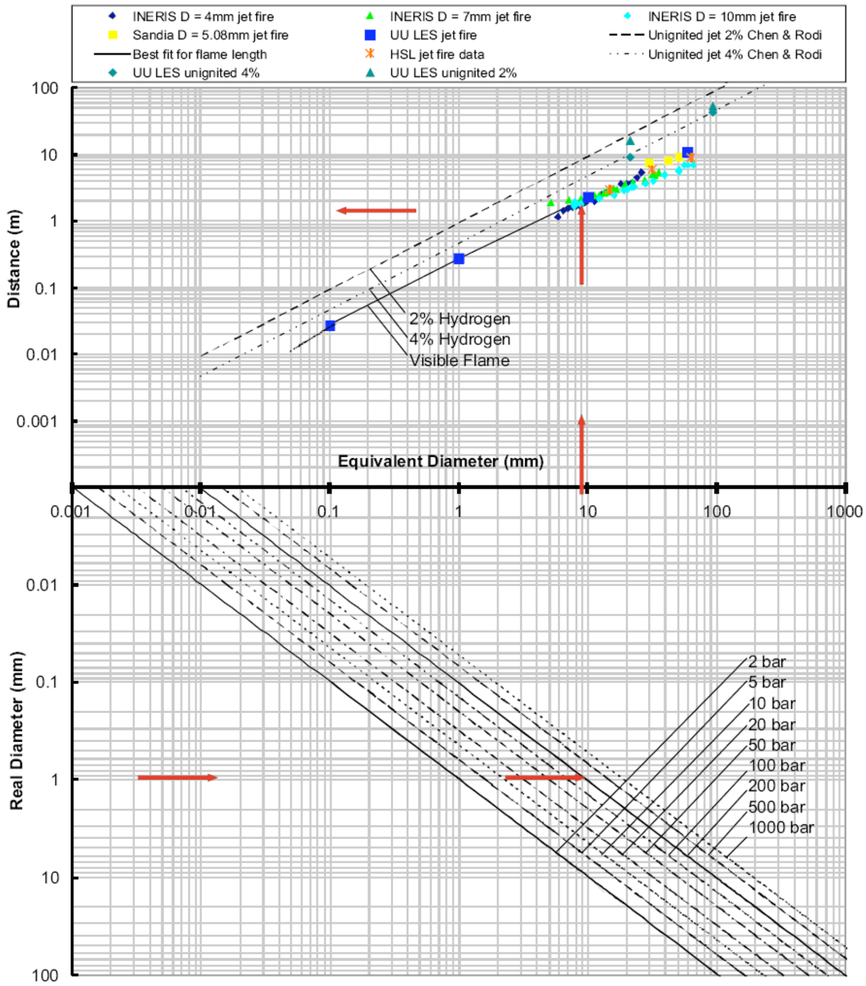

Figure 1 - Nomogram for calculation of flame length of high momentum jet fire by a physical size of leak and pressure in a storage[1]

Particular attention should be given to the design and location joints in the system that may require regular maintenance, or where mechanical joints will be frequently disturbed or made/broken as the likelihood of leaks in these areas is increased. The connection between the cylinder and the manifold is typical of these and should be checked with a suitable detection solution or suitable electronic gas detection device whenever the cylinder is changed[41].

Pipe routing should reflect consideration of factors such as risk from impact damage, formation of flammable mixtures in poorly ventilated areas, heat sources etc. Consequently, where pipe work passes through enclosed ducts, cavity walls etc, there should be no mechanical joints.

Piping should preferably be routed above ground; if underground pipe work is unavoidable, it should be adequately protected against corrosion. The position and route of underground piping should be recorded in the technical documentation to facilitate safe maintenance, inspection or repair. Underground hydrogen pipelines should not be located beneath electrical power lines.

Pipe work should be cleaned before being place into service using a suitable procedure for the type of containment, which provides a level of cleanliness required by the application.

Systems should be suitably purged using an inert gas (i.e. nitrogen) to prevent the existence of a hydrogen/air mixture. Purging can be by sweep purging, evacuation or repeated pressurisation

and venting cycles, using appropriately engineering and sited vent and purge connections. Also, consideration should be given to the asphyxiation hazards of using inert gases.

4.3 SITING

Requirements applicable to the siting of stationary fuel cell installations fuelled by hydrogen and of their attendant storage and hydrogen generation systems (the installation) will vary according to whether the installation is located in domestic dwellings, in commercial premises/buildings, or outside in the open air.

4.3.1 General requirements for both domestic/residential and commercial/industrial installations

The following general requirements apply to all systems whatever their location and should be taken into account in assessing that the risk is acceptable and has been reduced to as low as is reasonably practicable:

- The installation should be placed on firm foundations, capable of supporting it;
- Ensure that any area, enclosure or housing etc into which hydrogen may leak is designed to prevent the gas becoming trapped and is equipped with effective high and low level ventilation openings:
- The installation components, in particularly vent or exhaust outlets, should be sited giving due attention to adjoining doors, windows, outdoor air intakes and other openings into buildings;
- Air intakes shall be located in such a way that the fuel cell is not adversely affected by other exhausts, gases or contaminants;
- Exhaust outlet(s) should not be directed onto walkways or other paths of pedestrian travel
- Security barriers, fences, landscaping and other enclosures should not affect the required flow into or exhaust out of the installation;
- Any vents (from pressure relief valves or bursting joints, etc) should be piped to a safe area and any points of possible leakage should be in an area where any gas cannot accumulate or is freely ventilated. In addition care should be taken that vents do not release hydrogen adjacent to walls or along the ground as this may increase the extent of the flammable cloud or flame;
- Safety/separation distances where a release is foreseeable during normal operation should be determined on a case-by-case basis. Separation distances should be measured horizontally from those points in the system where, in the course of operation, an escape of hydrogen may occur. The most recent version of an appropriate code should be consulted for additional information on the appropriate use of separation distances. In circumstances where it is not practicable to use minimum separation distances, an acceptable situation may be achieved through the use of fire-resistant barriers, fire compartments, fire resistance, room-sealed appliances, appliance compartments, or other hydrogen safety engineering or risk reduction techniques;
- For all indoor locations the installation should comply with all applicable building regulations, particularly as they relate to heating and electrical appliances, fuel storage systems, conservation of fuel and power, protection against pollution, and more

generally to securing reasonable standards of health and safety for people in or about buildings and any others who may be affected by buildings or matter connected with buildings.

- For all indoor fuel cell locations, liquefied and gaseous hydrogen storage should either be located outside in the open air, in an appropriate dedicated unoccupied storage building, in an appropriately ventilated enclosure, or in a purpose designed indoor or underground facility, and should conform to recognised guidance.

4.3.2 Requirements specific to commercial/industrial premises

- The fuel cell and any associated equipment shall be suitably protected against unauthorised access, interference, vandalism or terrorist attack commensurate with the location and installation environment. Any security arrangements shall not compromise the requirement for effective ventilation.
- The fuel cell and associated equipment shall be suitably located to allow service, maintenance and fire department/emergency access and shall be supported, anchored and protected so that they will not be adversely affected by weather conditions (rain, snow, ice, freezing temperatures, wind, seismic events and lightning) or physical damage. Furthermore the placing of any components of the fuel cell system should not adversely affect required building exits, under normal operations or in emergencies.
- If practicable, the installation should be located in a normally unoccupied room built to appropriate fire-resistance standard and within an appropriate fire-resisting and non-combustible enclosure. Congestion, blockages and obstructions should be kept to an absolute minimum in the room as they may enhance flame acceleration in the event of an accident.
- The room in which the fuel cell and associated equipment are located shall provide a minimum of 30 minutes fire-resistance and be fitted with a suitable fire detection and alarm system.
- The installation should not be located in areas that are used or are likely to be used for combustible, flammable or hazardous material storage;
- Any potential sources of ignition, such as non-flameproof electrical light fittings, should be located well below any equipment from which hydrogen may leak and not immediately below horizontal bulkheads or impervious ceilings under which hydrogen may accumulate;
- For workplaces it is a legal requirement, under DSEAR, for the employer to identify fire and explosion hazards, classify areas where explosive atmospheres may exist, evaluate the risks and specify of measures to prevent or, where this is not possible, mitigate the effects of an ignition.
- All equipment (electrical or mechanical) within the identified hazardous zone shall be CE certified. Whenever reasonably practicable, the fuel cell and other hydrogen handling equipment shall be located at the highest level within the enclosure and physically isolated from any electrical equipment that is not ATEX-complaint or other potential sources of ignition.
- Gas-tight compartments, bulkheads and ventilation should as far as possible be used to reduce the likelihood of leaking hydrogen reaching potential ignition sources.

- Unless compliant with the EPS Regulations[13], the installation should be located away from areas where potentially explosive atmospheres may be present;
- The ventilation exhaust or other sources of emission that may contain dangerous substances must be released to a safe place. An appropriate hazardous zone should be identified around any foreseeable release point;
- The following additional factors should be taken into account in assessing that the risk is acceptable and has been reduced to as low as is reasonably practicable: smoking permitted areas; uncontrolled public areas; security barriers; emergency exits.

4.3.3 Emergency planning

It is recommended that an emergency plan should be in place wherever compressed gaseous or cryogenic fluids are produced, handled or stored[42]. This emergency plan should include the following:

- The type of emergency equipment available and its location;
- A brief description of any testing or maintenance programs for the available emergency equipment;
- An indication that hazard identification labeling is provided for each storage area;
- The location of posted emergency procedures;
- A list, including quantities, of compressed gases and cryogenic liquids and their materials safety data sheets (MSDS) or equivalent;
- A facility site plan including the following information:
    - Storage and use areas;
    - Maximum amount of each material stored or used in each area;
    - Range of container sizes;
    - The location of gas and liquid conveying pipes;
    - Locations of emergency isolation and mitigation valves and devices;
    - On and off positions of valves for those that are not self-indicating;
    - A storage and distribution plan that is legible and drawn approximately to scale showing the intended storage arrangement, including the location and dimensions of walkways.
- A list of personnel who are designated and trained to act as a liaison with the emergency services and who are responsible for the following:
    - Aiding the emergency services in pre-emergency planning;
    - Identifying the location of compressed gases and cryogenic fluids stored or used;
    - Accessing MSDS;

- Knowing the site emergency procedures.

4.4 EXPLOSION PREVENTION AND PROTECTION

For industrial installations DSEAR[24] and the EPS Regulations[13] apply, which require an hierarchical approach to explosion prevention and protection.

DSEAR requires the identification of the explosion hazards and the prevention or protection measures to be employed. The measures taken should be appropriate to the nature of the operation being undertaken, in order of priority and in accordance with the following basic principles:

- The prevention of the formation of explosive atmospheres, or where the nature of the activity does not allow that;
- The avoidance of ignition sources where an explosive atmosphere could exist; or
- If ignition sources cannot be eliminated, the employment of measures to mitigate the effects of an ignition.

This approach to explosion safety, using a range of explosion prevention measures and, if the explosion risk cannot be entirely eliminated, explosion protection measures, is referred to as integrated explosion safety. Guidance on the integrated explosion safety approach can be found in BS EN 1127-1:2007[43], which outlines the basic elements of risk assessment for identifying and assessing hazardous situations. The standard also specifies general design and construction methods to help designers and manufacturers to achieve explosion safety in the design of equipment, protective systems and components.

4.4.1 Prevention of explosive atmospheres

The first line defence in preventing an explosion is to ensure an explosive atmosphere never exists, either as a result of a leak generating an external explosive atmosphere, air ingress forming an explosive atmosphere inside the equipment, or having a process that operates with gas mixtures in the explosive range.

Hydrogen, due to its low viscosity, is particularly prone to leakage from piping, vessels, etc and therefore special attention should be paid to ensuring gas tight connections in any equipment containing hydrogen. The requirements for hydrogen containment and piping are discussed in section 4.2. For processes that operate at sub-atmospheric pressures, leakage of hydrogen will not be an issue but the possibility of air ingress, resulting in the formation of an internal explosive atmosphere, needs to be considered.

Ventilation can be used to prevent small leaks generating an explosive atmosphere by ensuring the escaping gas cannot accumulate to concentrations above the LEL. Ventilation is the air movement leading to replacement of a potentially dangerous atmosphere by fresh air. The following principles should be used to ensure that any foreseeable release of a dangerous substance cannot accumulate to a concentration that affects the safety of people and property:

- Wherever possible locate hydrogen storage/handling equipment outside;
- Estimate the maximum foreseeable release rate;
- Provide adequate high and low ventilation;

- Beware of low ceilings, canopies, covers and roofs;
- Ensure the dilution air is drawn from a safe place;
- Ensure vents and purges discharge to a safe place;
- Use computational fluid dynamics (CFD) for complex ventilation requirements.

It is always best to locate hydrogen storage/handling equipment in the open air, however precautions still need to be taken to ensure that a flammable atmosphere cannot accumulate:

- Avoid the use of low, impervious roofs, canopies or bulkheads;
- Avoid locations below eaves or other overhanging structures;
- Use a suitable, non-combustible security fence rather than a wall;
- Ensure adequate high- and low-level ventilation apertures where a wall around the storage system in unavoidable.

The size of any foreseeable leak into an enclosed or partially enclosed area should be used as the basis for any calculations of the ventilation requirements. The ventilation regime should be sufficient to ensure that the hydrogen concentration is normally maintained below 10% of the LEL (0.4% v/v for hydrogen), with only occasional temporary increases to 25% of the LEL. Some basic equations for a calculating degrees of ventilation are described in BS EN 60079-10:2003[44].

Two main types of ventilation are recognised:

a) Passive or natural ventilation: the flow of air or gases is created by the difference in the pressures or gas densities between the outside and inside of a room or enclosed space.

b) Active or forced (mechanical) ventilation: the flow of air or gas is created by artificial means such as a fan, blower, or other mechanical means that will push or induce an air flow through the system. The artificial ventilation of an area may be either general or local.

Natural ventilation can be provided by permanent openings. The location of the openings shall be designed to provide air movement across the room or enclosed space to prevent the unwanted quantities of hydrogen-air mixtures. Inlet openings for fresh air intakes should be located near the floor in exterior walls (and only in such a way so that they do not reintroduce air previously evacuated from the process area). Outlet openings should be located at the high point of the room in exterior walls or roof. Inlet and outlet openings shall each have a minimum total set area of the room volume. In the ANSI/AIAA Guide for Hydrogen and Hydrogen System[45], a minimum total ventilation area of 0.003 m^2/m^3 of room volume was set for the inlet and outlet openings. Discharge from outlet openings shall be directed or conducted to a safe location. Ventilation openings shall be designed so that they will not become obstructed during normal operation by dust, snow or vegetation in accordance with the expected application. In open air situations, natural ventilation will often be sufficient to ensure dispersal of any explosive gas atmosphere which arises in the area. For outdoor areas, the evaluation of ventilation should normally be based on an assumed minimum wind speed of 0.5 m/s, which will be present virtually continuously (EN 60079-10:2003[44]).

The effect of wind should be borne in mind when deciding vent orientation. Depending on the position of the vents, wind may impede or enhance the ventilation efficiency[46].

If it can be verified, natural ventilation should be permitted to provide all required ventilation and makeup air. If mechanical ventilation is required, the ventilation system shall be interlocked to the hydrogen process equipment to prevent process equipment from working in the absence of ventilation, and therefore shut it down upon loss of ventilation. It shall also be equipped with an audible and visual alarm in order to give a warning in case of failure. The ventilation unit shall be constructed and installed in such a way as to preclude the presence of mechanical and electrical sparking.

The forced ventilation of an area may be either general or local and, for both of these, differing degrees of air movement and replacement can be appropriate. Although forced ventilation is mainly applied inside a room or enclosed space, it can also be applied to situations in the open air to compensate for restricted or impeded natural ventilation due to obstacles. As in the case of natural ventilation, the dilution air used to artificially ventilate the area should enter at low level and be taken from a safe place. The ventilation outflow should be located at the highest point and discharge to a safe place outdoors. Furthermore, the mechanical means used to ventilate the enclosure should be suitable and in particular, the electrical motor(s) should not be located in the potentially contaminated exhaust air stream.

Suitable arrangements should be in place to detect when the ventilation system is failing to provide adequate ventilation. This may be based on the measurement of flow or pressure. This should raise an alarm and safely isolate the electricity supply outside the enclosure and the hydrogen supply outside the building with a normally closed (fail safe) valve. The fuel cell system should shut down safely upon loss of adequate ventilation.

The cooling/air supply fan or compressor present in many fuel cell modules may sometimes be suitable to provide effective ventilation. Where this approach is used, the air must be drawn from a safe place and the direction of the forced airflow must be compatible with the expected movement of any hydrogen release as a result of buoyancy, thermal effects etc.

Where differential pressure is used to prevent the ingress of hydrogen into adjoining compartments, the pressurisation air should drawn from/discharged to a safe place. Also, suitable fail safes should be in place to raise alarms/cause shutdown in the case of any detected loss of ventilation or differential pressure.

The dilution airflow and the number and location of flammable atmosphere detectors should be appropriate in complex systems or congested areas. An appropriate modelling technique should be used in these situations to ensure that pockets of flammable mixture will not accumulate and remain undetected.

In situations where other fuels such as methane, LPG etc are present in addition to hydrogen, the different densities and diffusivities need to be taken into account to ensure that the ventilation arrangements provided are adequate.

Ventilation is not recommended as a prevention measure for large leaks, for example from the catastrophic failure of pipe, as ventilation systems are unlikely to be able disperse large leaks quickly enough to prevent an explosive atmosphere accumulating. If ventilation is used as a prevention measure, then the reliability of the system has to be guaranteed and if the ventilation is only activated when a leak occurs then there must also be a reliable method, e.g. gas detectors, of detecting the leak. Guidance on the selection and location of gas detectors is given in Appendix 4.

There is a higher risk of an explosive atmosphere being present in equipment during commissioning, when items of equipment will initially contain air before assembly, or during maintenance when equipment is opened up for inspection/repair allowing air ingress. For these

operations, inerting can be employed to prevent an explosive atmosphere forming. Inerting is a technique by which the equipment is purged with an inert gas, such as nitrogen or carbon dioxide, until the oxygen concentration falls below the level required for flame propagation to occur. This is called the limiting oxygen concentration (LOC). The LOC depends on the inert gas being used, inerts with higher heat capacities being more efficient and giving higher values of LOC for a given flammable gas. For inerting with nitrogen the LOC for hydrogen is 5% v/v, while for inerting with carbon dioxide it is 6% v/v. Guidance on the application of the inerting technique can be found in the ISO published document PD CEN/TR 15282:2006[47].

Even if the formation of an explosive atmosphere cannot be prevented, then at a minimum, measures should be implemented to limit the extent of the explosive atmosphere. Such measures could include ventilation, use of gas tight seals on doors, pipe entry points, etc to prevent gas migration between rooms and compartments, and the use of a soft barrier. An example of a soft barrier is a curtain, made from polythene sheeting, which would allow easy access to the area where the gas source is, but would restrict the flow of gas to the surrounding areas.

4.4.2 Avoidance of ignition sources

If the formation of an explosive atmosphere cannot be prevented or the process operates with a flammable atmosphere, the next level of protection is the avoidance of ignition sources in areas where a flammable atmosphere may occur. The hazardous areas where explosive atmospheres could be formed have to be identified and classified according to the likelihood of an explosive atmosphere being present. For situations where hydrogen and/or other flammable gases or liquids may be present, the following classifications should be used where appropriate:

- Zone 0 – An area in which an explosive atmosphere is present continuously or for long periods. Only category 1 equipment should be used in these areas;

- Zone 1 – An area where an explosive atmosphere is likely to occur during normal operation. Only category 1 or 2 equipment should be used in these areas;

- Zone 2 – An area where an explosive atmosphere is not likely to occur during normal operation and, if it does occur, is likely to do so infrequently and will only last for a short period. Only category 1, 2 or 3 equipment should be used in these areas.

Guidance on identifying and classifying the hazardous areas is given in BS EN 60079-10:2003[44] and BS EN 1127-1:2007[43].

Electrical and non-electrical equipment appropriate for use in the different areas of the workplace should be determined once the hazardous areas have been identified and classified. The EN 60079 series of standards specifies the requirements and testing of electrical equipment for use in the different zones. Part 0[48] specifies the general requirements for the construction, testing and marking of electrical apparatus and components intended for use in hazardous areas where explosive gas/air mixtures exist under normal atmospheric conditions. Part 14[49] gives the specific requirements for the design, selection and erection of electrical installations in explosive gas atmospheres. These requirements are in addition to those for installations in non-hazardous areas. Part 17[50] covers the maintenance of electrical installations in hazardous areas and Part 19[51], the repair and overhaul for apparatus used in explosive atmospheres. Non-electrical equipment is covered by the BS EN 13463 series of standards, with Part 1[52] specifying the basic method and requirements for the design, construction, testing and marking of equipment. Methodology for the risk assessment of non-electrical equipment for use in potentially explosive atmospheres is given in BS EN 15198:2007[53].

The hazardous area classification should also be used to ensure that suitable controls are placed on all other foreseeable sources of ignition including hot work, smoking, vehicles, mobile phones and work clothing.

Precautions should also be taken to prevent the build-up of static charges that may lead to an incendive discharge. These may include:

- Ensuring that all pipe work is conductive and has effective electrical continuity, especially over mechanical joints such as flanges;

- Ensuring that all pipe work and equipment is effectively earthed;

- Carrying out and documenting appropriate earthing/continuity checks;

- Wearing antistatic clothing and footwear in hazardous areas.

Further information on the avoidance of hazards due to electrostatics can be found in the code of practice PD CLC/TR 50404:2003[54].

Appropriate protection is also required against the risk of lightning strike when designing outdoor fuel cell or hydrogen storage facilities.

4.4.3 Explosion mitigation

If explosive atmospheres may be present and ignition sources cannot be eliminated, then measures to mitigate the effects of the explosion, should an ignition occur, and prevent the explosion propagating to surrounding areas are required. There are a number of techniques available that can be employed to reduce the explosion pressure generated and/or contain the explosion within a given area.

4.4.3.1 Explosion venting

In this technique, weak areas (explosion vents) that fail early on in the explosion are deliberately incorporated in the item of equipment, venting the combustion products and so reducing the explosion pressure generated inside the equipment. There are a number of methods used to seal the vents, such as thin membranes, bursting discs, lightweight covers held in place by magnetic fasteners and spring loaded doors. The opening pressure of the covers and the size of the vents are chosen to give explosion pressures below that which would damage the equipment. It may, however, be acceptable to allow some damage to the equipment, e.g. bowing of panels, provided it does not result in damage to the adjacent area or injuries to nearby personnel. It should also be ensured that the explosion is vented to safe areas so it causes no damage or injuries. BS EN 14797:2006[55], BS EN 14994:2007[56] and NFPA 6857 provide guidance on the design of explosion relief systems and the methods of available for vent sizing.

4.4.3.2 Explosion suppression

Explosion suppression is achieved by injecting a suppressant agent, either water or a liquid or powder suppressant, into a developing explosion to quench it before the maximum explosion pressure is attained. Suppressing hydrogen explosions is particularly challenging due to the high flame speeds of hydrogen explosions. Basic requirements for the design and application of explosion suppression systems are given in BS EN 14373:2005[58].

4.4.3.3 *Isolation systems*

Explosion isolation is a technique that prevents an explosion pressure wave and a flame, complete isolation, or only a flame, partial isolation, from propagating via connecting pipes or ducts into other parts of the plant. The distinction between the two types is important as in some applications it may only be necessary to achieve flame isolation. The systems can be either be an active type, which requires a means of detecting the explosion and initiating an action to implement the isolation, or passive and requires no additional equipment to function. Examples of an active system are a quick acting valve, a complete isolation system, or an extinguishing barrier. The later system provides partial isolation by injecting a curtain of suppressant into the pipe or duct to quench the explosion. An example of a passive partial isolation system is a flame arrester. This device contains an arresting element, comprising a matrix of small apertures or convoluted gas pathways, with dimensions large enough to allow gas flow with minimal pressure drop, but small enough to quench and prevent the passage of flame through the element. A standard (prEN 15089[59]) is under development that will specify the general requirements for explosion isolation systems, excluding flame arresters, and the methods for evaluating the effectiveness of different systems. BS EN 12874:2001[60] specifies the performance requirements, test methods and limits for use of flame arresters.

4.4.3.4 *Containment systems*

An alternative mitigation technique to those that aim to reduce the explosion pressure is to use equipment, for example process vessels, strong enough to contain the explosion. Equipment intended to withstand an internal explosion are classed as one of two types. Explosion-pressure-resistant equipment is designed to withstand the expected internal explosion pressure without becoming permanently deformed. Explosion-pressure-shock resistant equipment is designed to withstand the expected internal explosion pressure without rupturing, but allowing for some permanent deformation. EN 14460:2006[61] specifies the requirements of the two classes of equipment.

4.4.3.5 *Blast walls*

Equipment and plant vulnerable to blast damage can be protected by blast walls. These are strong walls positioned between the item to be protected and the expected source of blast that will deflect the blast wave and thus reduce the intensity of explosion pressure experienced. They can also provide protection from missiles generated by the explosion. The possible beneficial and detrimental effects of blast walls on the dispersion of leaking gas need to be taken into account in the assessment of the explosion hazards. Depending on the circumstances, for example wind direction and site layout, blast walls may limit the spread of an explosive gas/air cloud. On the other hand, walls may extend the time an explosive cloud is present and thus the likelihood of an ignition, by inhibiting the dispersion of the gas by the wind. These effects are more likely to be important for gases other than hydrogen, as due to its low density there will be a significant upward dispersal due to buoyancy. An experimental and modeling programme on the effects of walls and barriers has been carried out within HYPER and details can be found on the project website[1].

4.5 HYDROGEN SENSING

As a colourless, odourless and tasteless gas, hydrogen cannot be detected by human senses, therefore, means should be provided to detect the presence of hydrogen in locations where leaks and/or accumulations may occur. When using hydrogen in confined spaces, the employment of a hydrogen detection system for early detection of leaks is essential to facilitate the activation of alarms, safety operations and where necessary, the safe evacuation of people. There are numerous hydrogen sensors/detectors commercially available operating on various principles.

When installing a hydrogen gas detection system, the following questions need to be considered:

- Which is the most suitable sensing technology?
- What are the appropriate alarm thresholds for the hydrogen detection system?
- How many sensors are required?
- Where should the sensors/detectors be located?

Consulting relevant standards, regulations and guidelines can assist in the choice and correct use of a particular type(s) of hydrogen detection system most suitable for an application. Technical standards for flammable gas detectors have existed for many years, although not specifically for hydrogen. The most useful among the technical standards are the BS EN 61779 series of standards[62], although they do not specifically focus on hydrogen. The development of a standard specific to the performance and testing of hydrogen detection apparatus is underway (ISO Technical Committee 197 - WG13). Further information on regulations, codes and standards relating to flammable gases and hydrogen is published in Chapter 6 of the HySafe Biennial Report on Hudrogen Safety[63] and some useful regulations codes and standards are also listed in Appendix 1.

Detection techniques, sensor positioning, alarm levels, sensor maintenance and calibration are discussed in Appendix 4.

4.6 FIRE PRECAUTIONS

Fire precautions are relevant for all aspects of the fuel cell installation, from the hydrogen generation, processing, storage, and piping, to the fuel cells. A fire can often lead to an explosion and, by the same token, an explosion can initiate a fire. It is important, therefore, that a fire and explosion risk assessment be carried out as a single exercise that considers all the fire and explosion hazards that can arise.

Fire precautions are often referred to as process fire precautions (PFP) and general fire precautions (GFP). PFP are special precautions that are required for the work activity being undertaken to prevent or reduce the likelihood of a fire occurring or to limit the extent of the fire. GFP are those basic measures taken to ensure people's safety in the event of a fire, e.g. general measures to prevent fire, means of escape, provision of fire extinguishers, fire detection and alarms and staff training.

General fire precautions for the workplace are set out in the Workplace Directive (89/654/EEC)[64], which specifies the minimum requirements for health and safety in the workplace. These requirements are implemented in England and Wales by the Regulatory Reform (Fire Safety) Order 2005[65], in Scotland by Fire (Scotland) Act 2005[66] and came into force on 1 October 2006. Under the new legislation fire certificates are no longer required and instead a risk-based approach becomes the primary method to manage fire risk in the workplace. Responsibility for compliance will rest with the Responsible Person. In the workplace, this is the employer and any other person who may have control of any part of the premises, e.g. the occupier or owner. The duty of the Responsible Person is to ensure that a suitable and sufficient fire risk assessment has been carried out for the site. This amongst other things covers: means of detecting and giving warning of a fire at the site; measures to reduce the risk of fire and its spread; means of escape from the site, provision of fire fighting measures; and the safety fire of fighters. A recently published British Standard, BS 9999:2008[67], gives recommendations and guidance on the design, management and use of buildings to achieve reasonable standards of fire safety for all people in and around buildings.

4.6.1 Overheating

The fuel cell, and any hydrogen generation and processing equipment must be designed and constructed in such a way as to avoid any risk of a fire being initiated by overheating. Some types of fuel cell operate at temperatures in the range of 600 to 1000^{0}C, so even under normal conditions a high standard of thermal insulation will be required to prevent nearby equipment from overheating.

4.6.2 Fire fighting

Fires involving hydrogen should not be approached without appropriate flame detection equipment due to the low visibility of hydrogen flames. Hydrogen fires should not be extinguished until the supply of hydrogen is shut off because of the danger of re-ignition or explosion of an accumulation of unburnt hydrogen. The recommended way of handling a hydrogen fire is to let it burn under control until the hydrogen flow can be stopped. Small hydrogen fires can be extinguished by dry chemical extinguishers or with carbon dioxide, nitrogen, and steam. Water in large quantities is the best way of extinguishing anything other than a small hydrogen fire, and is required for spraying adjacent plant to keep it cool and preventing fire spread. Water spray systems should be provided for hydrogen storage containers, grouped piping, and pumps where potential fire hazards exist. The system(s) shall be arranged to deliver a uniform spray pattern over 100 per cent of the container surface, pumps, and adjacent piping. Manual control stations shall be located outside the hazardous area, but within effective sight of the facility protected.

No attempt should be made to extinguish fires involving hydrogen or other flammable gas cylinders, unless they are in the open or in a well-ventilated area free of combustibles and ignition sources. Even if located in open or well-ventilated areas, extreme care should still be taken in attempting to extinguish the fire, as this may create a mixture of air and escaping gas that, if re-ignited, might explode. Under no circumstances should firefighters attempt to remove a burning cylinder. An appropriate exclusion zone should be set-up and the burning cylinder(s), and any surrounding cylinders and combustibles, should be kept cool by spraying them with water until the gas escape ceases and the fire extinguishes.

4.6.3 Emergency plan

A fire protection and emergency plan should be drawn up. Personnel should receive specific training in dealing with emergencies involving hydrogen. In particular they should know how hydrogen explosions and fires differ from those involving the more conventional gaseous fuels such as natural gas and LPG. One example of a difference, which is of particular relevance to hydrogen fires, is that hydrogen flames are often invisible, especially in bright sunlight, increasing the likelihood of people fleeing an incident or emergency workers inadvertently straying into a flame.

4.7 INTERCONNECTIVITY

Manufacturers of equipment intended to be connected to networks should construct such equipment in a way that prevents networks from suffering unacceptable degradation of service when used under normal operating conditions. In the UK Technical Note G83/1-1[68] covers the connection of small-scale generators to local power distribution networks.

5 PERMITTING ROUTE

Currently there is no formalised route for the approval of a hydrogen and fuel cell stationary installation.

Guidance on installation can be found in BS EN 62282-3-3 2008[2].

The permitting route required for a particular installation should be proportionate to the scale and complexity of the installation. Domestic or residential installations are likely to require a simpler permitting route than a commercial or industrial installation and for this reason different permitting routes are proposed for the two types of installation.

The approval checklist below is intended to apply to both new-build and retro-fitted installations.

5.1 OUTLINE APPROVAL CHECKLIST FOR COMMERCIAL/INDUSTRIAL INSTALLATIONS

5.1.1 Step 1 – risk assessment

Undertake a risk assessment to identify the hazards and the measures to be implemented to eliminate or mitigate their effects. The principal hazards will be fire and explosion ones (see 4.4 and 4.6), but other hazards, e.g. electrical, pressure and weather (for outdoor installations) related, also need to be considered. The hazards arising throughout the lifetime of the installation have to be covered by the assessment. This would include those hazards associated with the installation of the equipment, start up and shutdown of the equipment, delivery of consumables (e.g. gas cylinders) and the maintenance and repair of the equipment. Guidance on how to undertake a risk assessment can be found in Appendix 5.

For workplaces it is a legal requirement, under DSEAR, for the employer to identify the fire and explosion hazards, classify areas where explosive atmospheres may exist, evaluate the risks and specify measures to prevent, or where this is not possible mitigate the effects, of an ignition. Further information on explosion control and mitigation measures is given in 4.4.

5.1.2 EU Directives

The equipment used in the installation must comply with the essential health and safety requirements of all applicable EU Directives. Compliance confirmed by the CE marking for each applicable Directive (see 3.1 and Appendix 3).

For a hydrogen fuel cell installation the applicable Directives and the UK implementing regulations are:

ATEX Equipment Directive [EPS Regulations[13]] - Applies to any equipment (electrical or non-electrical) or protective system designed, manufactured or sold for use in a potentially explosive atmosphere.

Pressure Equipment Directive (PED) [Pressure Equipment Regulations[15]] - Applies to the design, manufacture and conformity assessment of pressure equipment with a maximum allowable pressure greater than 0.5 bar above atmospheric over the temperature range it is designed for.

Low Voltage Directive (LVD) [The Electrical Equipment (Safety) Regulations[18]] - Applies to electrical equipment designed for use with a voltage rating of between 50 and 1,000 V for AC and between 75 and 1,500 V for DC.

Electromagnetic Compatibility Directive (EMC) [The Electromagnetic Compatibility Regulations[17]] - Applies to commercially available equipment, or combinations of equipment made into a single unit, intended for an end user and liable to generate electromagnetic disturbance, or the performance of which is liable to be affected by such disturbance.

Gas Appliances Directive (GAD) [The Gas Appliances (Safety) Regulations[15]] - Applies to appliances burning gaseous fuels used for cooking, heating, hot water production, refrigeration, lighting or washing and having, where applicable, a normal water temperature not exceeding 105^{o}C. Note though fuel cells do not burn gaseous fuels and should be excluded from the scope of the Directive, guidance issued on what appliances are covered by the Directive includes fuel cells where the primary function is heating. The Directive also covers such components as safety, regulating and controlling devices which may fitted in the gas side of a fuel cell or a reformation unit for generating hydrogen.

Machinery Directive [Supply of Machinery (Safety) Regulations[19,20,21]] - Applies to machinery, interchangeable equipment, safety components, lifting accessories, chains, ropes and webbing, removable mechanical transmission devices and partly completed machinery. This would not apply to the fuel cell installation itself, but may apply to associated equipment required for operating the installation, e.g. a hoist for lifting gas cylinders.

Prototype equipment does not need to comply with EU Directives and be CE marked. Nonetheless it is recommended that the general principles of the essential health and safety requirements are taken into account in the design of a prototype installation.

5.1.3 Step 3 – other legislation

The installation needs to meet legislation dealing with planning approval, building regulations (see 3.3.1) and fire regulations (see 4.6). Installations that are connected to the electrical distribution network, for exporting surplus electricity back to the grid, will need to meet electrical regulations for interconnectivity of supplies (see 4.7).

5.1.4 Step 4 – installation issues

The equipment to be installed, and maintained, by a competent person. At present there is no national scheme in place for training and assessing the competency of persons to install hydrogen systems, although some manufacturers do have schemes for training installers and service engineers.

5.1.5 Step 5 – emergency responders

The local fire brigade to be informed of the location and type of installation and given the opportunity to visit the installation. Of particular interest would be the location and quantity of any hydrogen stored at the site.

5.2 OUTLINE APPROVAL CHECKLIST FOR DOMESTIC/RESIDENTIAL INSTALLATIONS

5.2.1 Step 1 – risk assessment

Undertake a risk assessment to identify the hazards and measures to be implemented to eliminate or mitigate their effects. For domestic installations at best a fairly basic risk assessment will be required and may not be required at all in some cases, e.g. for an integrated CHP system. In these cases it will be sufficient that the equipment is installed according to the manufacturer's instructions, as in drawing up these instructions the manufacture will have undertaken a risk assessment. Guidance on how to undertake a risk assessment can be found in Appendix 5.

5.2.2 Step 2 – EU Directives

For residential installations there is no legal requirement to use ATEX compliant equipment as the ATEX Directives only apply to the workplace. Pressure equipment will still need to comply with the requirements of PED and electrical equipment with LVD and ECM. Fuel cells where the primary function is heating will have to comply with GAD and it is also recommended that gas safety, regulating and controlling devices on the installation meet the requirements of GAD. For further information on these Directives see section 5.1.2.

5.2.3 Step 3 – other legislation

The installation needs to meet national legislation dealing with planning approval, building regulations and fire regulations. For residential applications they will probably only need to comply with the building regulations (see 3.3.1). These as well as dealing with construction requirements of the building also deal with issues including fire safety, ventilation, sound insulation and energy efficiency. Installations that are connected to the electrical distribution network, for exporting surplus electricity back to the grid, will need to meet national electrical regulations for interconnectivity of supplies (see 4.7).

5.2.4 Step 4 – installation issues

The equipment to be installed, and maintained, by a competent person. At present there is no national scheme in place for training and assessing the competency of persons to install hydrogen systems, although some manufacturers do have schemes for training installers and service engineers.

5.2.5 Step 5 – emergency responders

The local fire brigade to be informed if there will be hydrogen stored, e.g. gas cylinders, at the premises. It is also recommended that the property insurers are informed of the installation.

6 APPENDIX 1 – USEFUL CODES AND STANDARDS

Table 1.1 lists useful codes and standards. Codes and standards are under continuous update and review. For the latest status of the hydrogen and fuel cell codes and standards the user is referred to: http://www.fuelcellstandards.com.

Table 1.1 - Listing of useful codes and standards

Application/topic	Applicable codes and standards
Hydrogen system specifications	BS EN 62282-3-1: 2007. Fuel cell technologies – Part 3.1:Stationary Fuel Cell Power Systems – Safety.
	BS ISO 16110-1:2007. Hydrogen generators using fuel processing technologies. Safety.
	Supply of Machinery (Safety) Regulations.
	The Gas Appliances (Safety) Regulations 1995
	EN 50465: 2008. Gas appliances-Fuel cell gas heating appliance nominal heat input up to 70kW.
	BS EN 13611: 2007. Safety and control devices for gas burners and gas-burning appliances - general requirements.
	BS EN 161:2002. Automatic shut-off valves for gas burners and gas appliances.
	BS EN 298:2003. Automatic gas burner control systems for gas burners and gas burning appliances with or without fans.
	BS EN 437:2003. Test gases. Test pressures. Appliance categories.
	BS EN 483:1999. Gas-fired central heating boilers. Type C boilers of nominal heat input not exceeding 70 kW.
	BS EN 677:1998. Gas-fired central heating boilers. Specific requirements for condensing boilers with a nominal heat input not exceeding 70 kW.
	BS EN ISO 12100-1:2003. Safety of machinery. Basic concepts, general principles for design. Basic terminology, methodology.
	BS EN ISO 12100-2:2003. Safety of machinery. Basic concepts, general principles for design. Technical principles.
	BS EN 50165:1997. Electrical equipment of non-electric appliances for household and similar purposes. Safety requirements.
	BS EN 60079-14:2008. Explosive atmospheres. Electrical installations design, selection and erection.
	BS EN 60079-17:2007. Explosive atmospheres. Electrical installations inspection and maintenance.
	BS EN 60079-19:2007. Explosive atmospheres. Equipment repair, overhaul and reclamation
	BS EN 60204-1:2006. Safety of machinery. Electrical equipment of machines. General requirements

Hydrogen system specifications	BS EN 60335-1:2002. Specification for safety of household and similar electrical appliances. General requirements.
	BS EN 60529:1992. Specification for degrees of protection provided by enclosures (IP code).
	BS EN 60730 series. Automatic electrical controls for household and similar use.
	BS EN 60950-1:2006. Information technology equipment. Safety. General requirements.
	BS EN 61000-6-2:2005. Electromagnetic compatibility (EMC). Generic Standards. Immunity for industrial environments.
	BS EN 61000-6-4:2001. Electromagnetic compatibility (EMC). Generic standards. Emission standard for industrial environments.
	ANSI/AIAA G-095-2004. Guide to Safety of Hydrogen and Hydrogen System. American National Standards Institute/American Institute of Aeronautics and Astranautics.
Fire safety	Regulatory Reform (Fire Safety) Order 2005.
	Fire (Scotland) Act 2005.
	PD 6686:2006. Guidance on directives, regulations and standards related to prevention of fire and explosion in the process industries.
Hydrogen systems installation	BS EN 61779 series (Parts 1 to 5). Electrical Apparatus for the Detection and Measurement of Flammable Gases.
	BS EN 60079-29-1:2007. Explosive atmospheres. Gas detectors. Performance requirements of detectors for flammable gases.
	BS EN 60079-29-2:2007. Explosive atmospheres. Gas detectors. Selection, installation, use and maintenance of detectors for flammable gases and oxygen.
	BS EN 62282-3-3: 2008. Fuel cell technologies – Part Stationary fuel cell power systems – Installation.
	EN 60079-10:2003. Electrical apparatus for explosive gas atmosphere. Classification of hazardous areas.
	HSG243. Fuel cells – Understand the hazards, control the risks. HSE Books.
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	BS EN 62282-3-3:2008. Fuel cell technologies – Part 3-3: Stationary fuel cell power systems – Installation.
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7 APPENDIX 2 – CASE STUDIES

The aim of the case studies undertaken as part of the HYPER project was to review and look at a broad range of installations and environments. By collecting this information it was hoped to compare best practise and harmonise local technical and non-technical variations. One of the UK case studies is reproduced below as an example of the type of installation that is currently operating in the UK. Further information on the case studies can be found on the HYPER website (www.hyperproject.eu).

DUDLEY, UNITED KINGDOM

1 Details of the Fuel Cell System

Application	:Combined heat and power
Customer/user	:Black Country Housing
Country	:England
City/Town	:Dudley West Midlands
Date	:2008/2009

Hyper Partner :HSL

Fuel Type:

Natural gas	YES	Hydrogen		Other *	

** Description:* *Natural Gas*

Status of development:

Prototype		Verification model	YES	Serial model		Other *	

** Description: Verification model*

CE Certification (for each component): THE WHOLE SYSTEM WAS CE MARKED

Component Name	CE Certification			
1.Stack	YES 1)		NO 2)	
2.H2 Supply system	YES 1)		NO 2)	
3.Electrical supply/inverter	YES 1)		NO 2)	
4.Control panel	YES 1)		NO 2)	
5.Heat exchanger	YES 1)		NO 2)	
6.Heat Store				
7. Electrical supply				
8.Battery Pack				

1) Which directives were used?

Hazop performed and Risk Assessment with HSE.
Planning authority consulted but they said it was outside their control.
Building control advised to treat it as an outside experiment.
Fire Brigade did not have a procedure – one was written by Richard Baines which they adopted.
Supply of gas (BOC) covered by Gas Regs
This procedure was used for 1st installation (2003) was adopted again.
Inform grid the system is going to be connected or disconnected (G83).

Which standards were used?

IGEM (Institution of gas engineers and managers) and IET (Institution of engineering and technology)

Who certified each component/the overall system?

BAXI had the system CE marked in Germany

- Please provide a copy of the certificate of conformance.

2)	Was a risk analysis carried out? YES

- Please provide HAZOP information.
- Please provide information regarding to safety measures taken (i.e. fire protection, ventilation, safety sensor, etc)

The system was housed in a wooden shed it was treated more as a natural gas system would have been treated. Fitted with leak detectors.

Nominal data:

Power out (kWe)	1.5kW
Heat out (kWth)	3.0kw
Fuel gas supply pressure (bar)	18 to 25 mbar
Voltage (V)	230
Frequency (Hz)	50
Ambient temperature range (°C)	
IP-rating	
Dimensions (m)	100cm x 73 cm x 185 cm
Weight (kg)	350

2 Installation

Location:

	Indoor	Outdoor
Remote		
Industrial		
Residential	Yes (lean-to shed)	

Additional information:
(e.g. single/multi family home, rooftop, laboratory, etc)

Single family home. Located in a shed attached to the house.

What affected your choice of site location?

Availability of site.

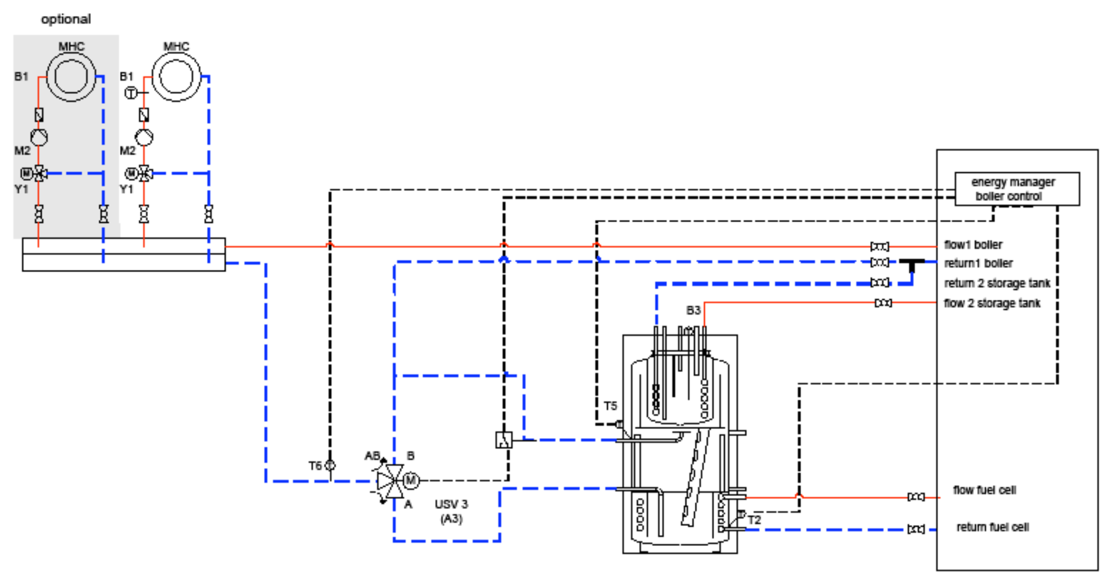
Installed by:

	Name, contact details
Installation company	Energised Ltd
Manufacturer	BAXI INNOTECH GmbH)
Service company (maintenance)	Energised
Other	

Please provide copies of installation manuals, service & operational manuals and training material.

2.1 Before & during installation

Schematic drawing of installation (electrical & mechanical):



Site evaluation:
1. What safety and security measures were taken for each component of the fuel cell system? (e.g. ventilation, fire protection, sensors, barriers, walls, locks)

Considered under HAZOP and under site choice.

Fuel supply:

Piped	YES	Generated on site		Stored on site [1)]	

1) Describe the fuel storage and any safety devices related to the storage, (e.g. number of cylinders used, size of tank used, storage pressure, materials used etc)

Natural Gas

2) Describe fuel piping used between components (material, length, internal and external diameter if known, shape connections, etc):

N/A

3) Describe what precautions were taken if the piping went through a wall (type of wall, type of sealing, piping instructions, fire protection, smoke protection, etc):

N/A

If the fuel cell was connected to a grid or appliance, what criteria had to be fulfilled?

The fuel cell was connected to the grid. Standard connection criteria for connection of distributed power generation to local distribution network was used (G83/1-1 2008 Engineering Recommendations).

2.2 After installation

What training did the installers, users and service personnel receive?

BAXI trained the installer and service personnel. No intervention by the user.

What emergency procedures are/were in place?

Fire Brigade were made aware of location of installation and a special tel number was issued in case of emergencies. Remotely monitored by (PLC) by BAXI.

If an approval route was necessary, describe by whom and what was needed?

The system was CE marked and similar procedures were followed as 1st installation.

Was any commissioning of the installation carried out? If so please provide details.

Commissioned in lab and then re-commissioned on site by manufacturer

Please describe the service procedure?

Re-commissioned on every service – period of service based on usage, running time and stops and starts

3 Lessons learned

What were the challenges/hurdles for approval?

Public perception of H2 (not good)
Fear of H2
No standards for installation in place lack of guidance
Is it gas or electrical?
Lack of knowledge within industry

What were the challenges/hurdles for installation?

Peripheral trades e.g. engineers and electricians were not sure of what to do.
Integrating the system with existing structures.

What problems were caused by techniques?

Small issue with lifting gear.

What problems were caused by administration, agencies?

N/A

What difficulties did the installer experience?

Lack of knowledge within industry.
I.T difficulties with German software, internet transfer and protocol.

What difficulties were experienced by the customer?

None

Describe any modifications to the installation process?

N/A

In your opinion, if a leak were to occur in the system, where would it be most likely to occur and what would be the most likely causes of the leak? (Describe multiple situations if necessary.)

N/A

8 APPENDIX 3 – CE CERTIFICATION

1. Check list

The following check-list should be used when seeking CE certification.

- Identify the directive(s) that are applicable to the different components of the fuel cell system.
- Identify the conformity assessment procedure that must be taken for each component being certified, whether self-declaration or assessment by a Notified Body or a combination of these.
- Be aware of when the directive(s) come into force.
- Identify if there are any Harmonised European Standards applicable to your product.
- Ensure the components of the fuel cell system comply with the essential requirements of the directive(s) used.
- Maintain technical documentation (see section 2) required by the directive(s). Your technical documentation should support your compliance with the requirements of the directive. It is essential to retain this documentation.
- Provide, in particular, the necessary information, such as instructions;
- Prepare the Declaration of Conformity and the required supporting evidence. The Declaration of Conformity along with the technical documentation should be available to competent authorities (EU Members) upon request.
- Check that no other purely national requirements exist in the countries where the product will be sold. These may include national standards, labelling or packaging requirements.
- Affix CE marking on your product and/or its packaging and accompanying literature as stated in the directive. In order to ensure the same quality for the CE marking and the manufacturer's mark, it is important that they be affixed according to the same techniques. In order to avoid confusion between any CE markings which might appear on certain components and the CE marking corresponding to the machinery, it is important that the latter marking be affixed alongside the name of the person who has taken responsibility for it, namely the manufacturer or his authorised representative.

2. Technical file

The technical file must demonstrate that the equipment complies with the requirements of the relevant directive(s). It must cover the design, manufacture and operation of the equipment to the extent necessary for assessment. The technical file must be compiled in one or more official Community languages, except for the instructions for the machinery, for which the special provisions apply and are described in the relevant directive(s).

The technical file shall comprise a construction file including:

- A general description of the equipment;

- The overall drawing of the equipment and drawings of the control circuits, as well as the pertinent descriptions and explanations necessary for understanding the operation of the equipment;

- Descriptions and explanations necessary for the understanding of said drawings and schemes and the operation of the electrical equipment;

- Full detailed drawings, accompanied by any calculation notes, test results, certificates, etc, required to check the conformity of the equipment with the essential health and safety requirements.

- The documentation on risk assessment demonstrating the procedure followed.

This documentation shall include:

- A list of the essential health and safety requirements which apply to the equipment;

- The description of the protective measures implemented to eliminate identified hazards or to reduce risks and, when appropriate, the indication of the residual risks associated with the equipment;

- The standards and other technical specifications used, indicating the essential health and safety requirements covered by these standards;

- Any technical report giving the results of the tests carried out either by the manufacturer or by a body chosen by the manufacturer or his authorised representative;

- A copy of the instructions for the equipment;

- Where appropriate, the declaration of incorporation for included partly completed equipment and the relevant assembly instructions for such equipment;

- Where appropriate, copies of the EC declaration of conformity of equipment or other products incorporated into the equipment;

- Where appropriate, for pressure systems, documentation relating to compliance with the materials specifications by using materials which comply with harmonised standards, by using materials covered by a European approval of pressure equipment materials or by a particular material appraisal;

- A copy of the EC declaration of conformity;

- Results of design calculations made, examinations carried out, etc;

- Test reports.

For series manufacture, the internal measures that will be implemented to ensure that the equipment remains in conformity with the provisions of the relevant directive(s).

The manufacturer must carry out necessary research and tests on components, fittings or the completed equipment to determine whether by its design or construction it is capable of being assembled and put into service safely. The relevant reports and results shall be included in the technical file.

The technical file must be made available to the competent authorities of the member states for at least 10 years following the date of manufacture of the equipment or, in the case of series manufacture, of the last unit produced. The technical file does not have to be located in the territory of the Community, nor does it have to be permanently available in material form. However, it must be capable of being assembled and made available within a period of time commensurate with its complexity by the person designated in the EC declaration of conformity. The technical file does not have to include detailed plans or any other specific information as regards the sub-assemblies used for the manufacture of the equipment, unless knowledge of them is essential for verification of conformity with the essential health and safety requirements.

3. EC declaration of conformity of the equipment

This declaration relates exclusively to the equipment in the state in which it was placed on the market, and excludes components that are added and/or operations carried out subsequently by the final user. The EC declaration of conformity must contain the following particulars:

- Business name and full address of the manufacturer and, where appropriate, his authorised representative;
- Name and address of the person authorised to compile the technical file, who must be established in the Community;
- Description and identification of the equipment, including generic denomination, function, model, type, serial number and commercial name;
- A sentence expressly declaring that the equipment fulfils all the relevant provisions of the relevant directive(s) and where appropriate, a similar sentence declaring the conformity with other directives and/or relevant provisions with which the equipment complies. These references must be those of the texts published in the Official Journal of the European Union;
- Where appropriate, the name, address and identification number of the notified body which carried out the EC type-examination and the number of the EC type-examination certificate;
- Where appropriate, the name, address and identification number of the notified body which approved the full quality assurance system;
- Where appropriate, a reference to the harmonised standards used;
- Where appropriate, the reference to other technical standards and specifications used;
- The place and date of the declaration;
- The identity and signature of the person empowered to draw up the declaration on behalf of the manufacturer or his authorised representative.

9 APPENDIX 4 – HYDROGEN DETECTION TECHNIQUES

There are several types of hydrogen sensors depending on its intended use. The electrochemical, catalytic and thermal conductivity detectors (TCD) are mainly used in the industries where the hydrogen risk is present. The metal oxide semi-conductor-based sensor (MOS) is most often used in research laboratories, whereas the MEMS (micro-electro-mechanic system) are used in the aeronautic and aerospace industries. Other less common but still commercially available sensors include gas field effect (GFE) type sensors and acoustic sensors. The various types of hydrogen detection technologies currently in use are described in detail in Chapter 5 of the HySafe Biennial Report on Hydrogen Safety (BRHS)[1] together with a description of emerging technologies for hydrogen detection.

Some important factors to consider in the selection of a hydrogen sensor include accuracy, measuring range, response time, ambient working conditions, lifetime and stability (see ISO/TR15916[2]). A market investigation on the performance of commercially available sensors has been performed (see HYSAFE deliverable D5.4[3]); the investigation was based on the technical information (product specifications, datasheets) made available by manufacturers.

Some general hydrogen performance targets for hydrogen safety sensors are given below[4]:

- Measurement range:0.1–10% H_2 in air
- Operating temperature: -30–+80 °C
- Humidity range: 10-98%
- Response time: t[90] < 1 sec
- Accuracy: 5%
- Lifetime: 5 yrs

Considering these performance targets and the capabilities of commercially available hydrogen detection systems shortcomings of current detection techniques are highlighted in Table 4.1.

Table 4.1 - Indications where commercially available sensors meet or fail to meet current performance targets

Criteria	Target		Electrochem		Catalytic		MOS		Acoustic		TCD		GFE	
Measuring Range %	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	0.1	10	✓	×	✓	×	✓	×	✓	✓	✓	✓	✓	×
Temperature Range / °C	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	-30	+80	×	×	×	×	✓	✓	×	✓	✓	×	✓	✓
Humidity Range %RH	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	10	98	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	×
Response Time t[90] / s	<1		×		×		×		✓		×		×	
Accuracy %	5		-		✓		×		×		✓		-	
Lifetime / yrs	5		×		✓		✓		✓		✓		-	

Due to the considerable differences in the various requirements for indoor applications, no sensor type is currently capable of meeting all performance target sets. Each detection technology has advantages and disadvantages depending on its intended application. When

considering a hydrogen detector for a particular application, the desired performance capabilities and ambient conditions for the application should be considered.

H_2 sensors positioning

The correct location of reliable sensors is crucial for timely detection and warning of hydrogen leaks before an explosive mixture is formed. Recommended locations for sensors include[2,5,6]:

- Evaluate and list all possible leak or spill sources to be monitored (valves, flanges, connections, bellows, etc) and provide valid justification for sources not monitored;
- At hydrogen connections that are routinely separated (for example, hydrogen refuelling ports);
- Locations where hydrogen could accumulate;
- In building air intake ducts, if hydrogen could be carried into the building;
- In building exhaust ducts, if hydrogen could be released outside the building.

The following points should also be considered[4]:

1. An understanding of how a gas leak disperses is required to choose the correct location to install the detection device(s). Hydrogen, being less dense than air, will rise when released and disperse rapidly.

2. When thinking of the location of hydrogen sensors/detectors, take the response time into consideration.

3. The LEL used shall be the LEL of the gas or gas mixtures.

4. When positioning detectors, local airflow also needs to be considered. Intuitively hydrogen detectors should be placed above a potential leak source however airflow may carry the hydrogen 'downstream', away from the detector and before reaching the ceiling. In that case detection may be delayed or even prevented.

5. Temperature can also have an effect on the dispersion of a gas. As hot air rises a layer of lower density air forms at the ceiling creating a 'thermal barrier' which may slow the diffusion of leaking hydrogen enough to delay detection at the sensor.

6. A combustible gas detector that meets the above requirements should be provided for all indoor or separately controlled gas compressors.
7. When hydrogen is stored as a cryogenic liquid and leaks, its density is initially greater than air causing it to settle to the ground before heating up, becoming lighter than air and eventually rising.

8. Dilution of hydrogen increases the further the detector is from the site of the leak. As a result the actual hydrogen concentration can be higher than the concentration indicated by the detection device when the device is located far from the leak site. For this reason detectors should be placed close to a potential leak site and should be sufficient in number to cover the installation.

9. It is recommended that a hydrogen sensor be placed at the most elevated point in an enclosed space.

10. If a forced ventilation system is installed then a sensor should be placed where the ventilation is applied.

Alarm levels

Alarms associated with hydrogen detection should be set as low a level as possible (≤ 10% LEL) without causing false alarms and should provide time to respond in a appropriate manner. Where the detection/shutdown system is a key part of the risk management system it should conform to an appropriate standard, e.g. EN 50073:1999[7].

Hydrogen system operators should have a portable hydrogen detector available for their use.

Once an alarm is triggered shutdown of the system should occur as quickly as possible to minimise the hydrogen inventory and hence the potential consequences of an ignition.

Ideally alarms should be audible and visible. Automatic corrective actions are actions that can be automatically triggered including forced ventilation, isolation of electrical components, isolation of hydrogen storage and auto-shutdown.

Hydrogen sensors maintenance and calibration

The performance of most sensors/detectors deteriorates with time, the rate depending on the type of sensor/detector and the operating conditions (e.g. dusty, corrosive or damp environment). Functioning must be checked with the frequency recommended by the manufacturer. Checking should include:

- appropriate cleaning, especially the head of the detector, to allow gas to reach the sensitive element;
- regular inspections for possible malfunctions, visible damage or other deterioration;
- that a zero reading is obtained in a clean atmosphere;
- that a correct response is obtained for exposure to a known concentration;
- that, if data logging is required, the logging period is appropriate for all data points over the required measurement time and can be stored in memory;
- the battery level, for portable instruments.

The best means to determine maintenance intervals for a sensor/detector is based on experience learned from use. For new installations it may be wise to carry out maintenance frequently at first (perhaps weekly), increasing the time intervals (to, perhaps, monthly) as confidence grows on the basis of the maintenance records with experience in the installation. Information on maintenance protocol should be found in the user manual supplied by the manufacturer.

References

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4. InsHyde Project Deliverable D113. Initial guidance for using hydrogen in confined spaces – Results from InsHyde. www.hysafe.org/inshyde.

5. IEC 62282-3-3:2007 Fuel cell technologies – Part 3-3: Stationary fuel cell power systems – Installation.

6. NASA NSS 1740.16 Safety Standard for Hydrogen and Hydrogen Systems. National Aeronautics and Space Administration (NASA).

7. EN 50073:1999. Guide for selection, installation, use and maintenance of apparatus for the detection and measurement of combustible gases or oxygen.

10 APPENDIX 5 – RISK ASSESSMENT METHODOLOGY

An example of the steps necessary to complete a risk assessment is given below. This is not the only way to perform a risk assessment but this method helps to assess health and safety risks in a straightforward manner. The law does not expected all risks to be eliminated, but protection of people as far as 'reasonably practicable' is required.

Step 1 - Identify the hazards.

The types of hazards identified and the methods used will vary according to the complexity of the installation.

Areas to be considered when identifying the hazards may/will include;

Site location, site evaluation, hydrogen storage location, security, choice of materials, access, deliberate attack and vandalism, impact, ventilation, fire protection, location of safety sensors, connection to grid.

A suitable emergency plan should be drawn up in the event of a leak or fire.

Step 2 - Decide who may be harmed and how.

For each hazard identified in Step 1 assess who might be harmed and how.

Step 3 - Evaluate the risks and decide what to do about them

Consideration should be given to removing the hazard and if that is not practical, how the hazard can be reduced or controlled.

Step 4 - Record and implement the findings

The risk assessment should show that all significant hazards have been recorded and addressed and how the hazards will be eliminated or if they cannot be eliminated how their effects will be minimised. Employees must be informed about the outcome of the risk assessment. The precautions taken should be reasonable and if there is a residual risk it should be low.

Step 5 - Review the Risk Assessment and update if and when necessary

Records of the installation, maintenance checks and servicing should be kept.

Any changes to the installation, work activities, process or incidents should be recorded and the risk assessment reviewed and if necessary additional safety measures implemented.

A risk assessment can be considered as "suitable and sufficient" if it has:

- correctly identified all the hazards
- disregarded inconsequential risks and those trivial risks associated with life in general
- determined the likelihood of injury or harm arising

- identified those who may be at particular risk, such as pregnant, elderly or disabled persons
- taken into account any existing control measures
- identified any specific legal duty or requirement relating to the hazard
- provided sufficient information to decide upon appropriate control measures, taking into account the latest scientific developments and advances
- enabled the remedial measures to be prioritised
- will remain valid for a reasonable period of time

A free download of an HSE leaflet giving more detail on the five steps to risk assessment is available at www.hse.gov.uk/pubns/indg163.pdf. Further assistance in producing risk assessments is available in books, videos and training sessions. Many consultancy organisations exist that can assist with or prepare risk assessments for their clients.

11 APPENDIX 6 – ABBREVIATIONS

AFC	alkaline electrolyte fuel cell
ATEX	ATmosphères EXplosibles (Explosive atmospheres)
BRHS	Biennial Report on Hydrogen Safety
CE	Conformité Européenne/European Conformity (the marking used to show conformity with a European Directive)
CFD	computational fluid dynamics
CHP	combined heat and power
CNG	compressed natural gas
DSEAR	Dangerous Substances and Explosive Atmosphere Regulations
EC	European Commission
EHSR	essential health and safety requirements
EIGA	European Industrial gases Association
EMC	Electromagnetic Compatibility Directive
EN	European norm (standard)
EPS	Equipment and Protective Systems for Use in Potentially Explosive Atmospheres Regulations
EU	European Union
FC	Fuel cell
GAD	Gas Appliances Directive
GFP	general fire precautions
HSE	Health and Safety Executive
HSL	Health and Safety Laboratory
IEC	International Electrotechnical Commission
IPG	Installation Permitting Guidance
ISO	International Standards Organisation
LEL	lower explosion limit

LOC	limiting oxygen concentration
LPG	liquefied petroleum gas
LVD	Low Voltage Directive
MCFC	molten carbonate fuel cell
MSDS	materials safety data sheet
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
PACF	phosphoric acid fuel cell
PED	Pressure Equipment Directive
PER	Pressure Equipment Regulations
PEMFC	polymer electrolyte membrane fuel cell
PFP	process fire precautions
SOFC	solid oxide fuel cell
STREP	Specific Targeted Research project
UEL	upper explosion limit

12 APPENDIX 7 – REFERENCES

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Installation permitting guidance for hydrogen and fuel cell stationary applications: UK version

The HYPER project, a specific targeted research project (STREP) funded by the European Commission under the Sixth Framework Programme, developed an Installation Permitting Guide (IPG) for hydrogen and fuel cell stationary applications. The IPG was developed in response to the growing need for guidance to foster the use and facilitate installation of these systems in Europe. This document presents a modified version of the IPG specifically intended for the UK market. For example reference is made to UK national regulations, standards and practices when appropriate, as opposed to European ones.

The IPG applies to stationary systems fuelled by hydrogen, incorporating fuel cell devices with net electrical output of up to 10 kWel and with total power outputs of the order of 50 kW (combined heat + electrical) suitable for small back up power supplies, residential heating, combined heat-power (CHP) and small storage systems. Many of the guidelines appropriate for these small systems will also apply to systems up to 100 kWel, which will serve small communities or groups of households. The document is not a standard, but is a compendium of useful information for a variety of users with a role in installing these systems, including design engineers, manufacturers, architects, installers, operators/maintenance workers and regulators.

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